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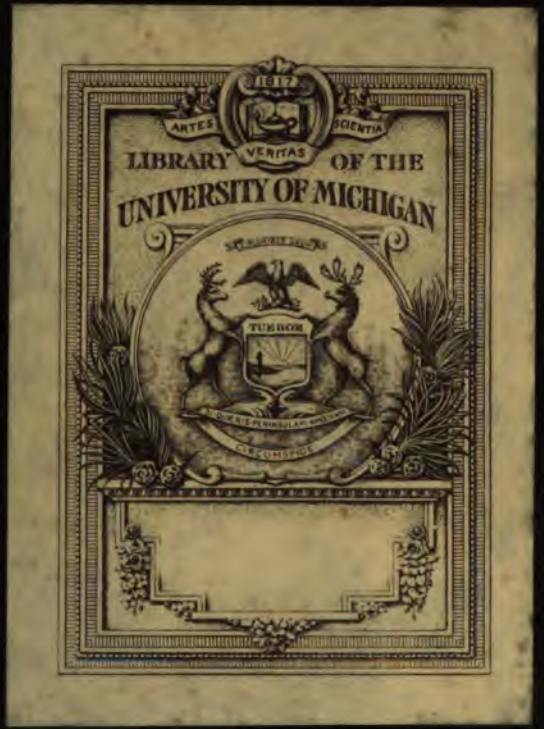
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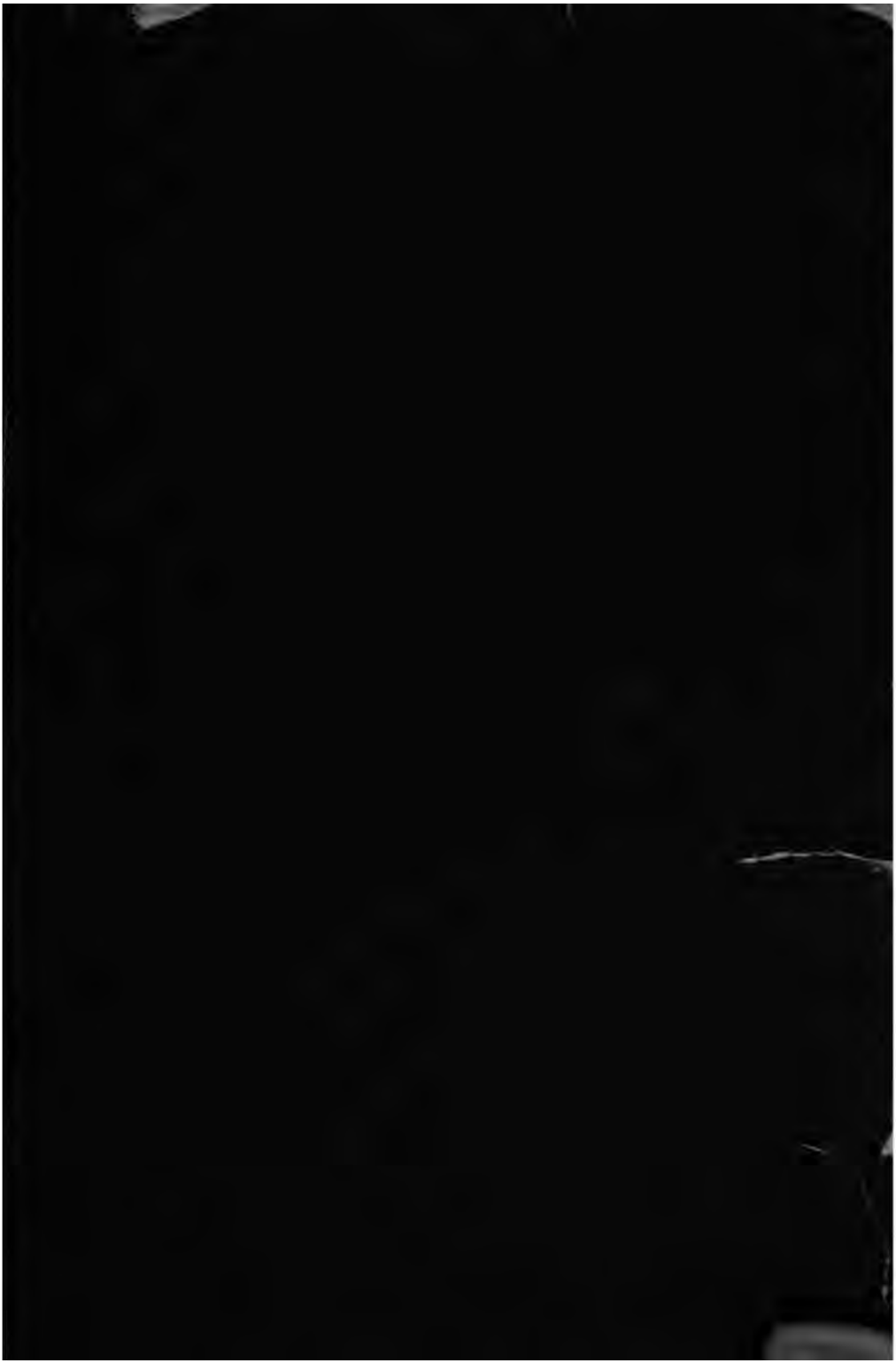

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THE VISIBLE UNIVERSE

CHAPTERS ON THE ORIGIN AND CONSTRUCTION OF THE HEAVENS

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BY

J. ELLARD GORE, F.R.A.S.

Member of the Royal Irish Academy; Fellow of the Royal Geological Society of Ireland; Associate Member of the Institution of Civil Engineers; Honorary Member of the Liverpool Astronomical Society; Corresponding Member of the Astronomical and Physical Society of Toronto

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"A knowledge of the construction of the heavens has always been the ultimate object of my observations."

SIR W. HERSCHEL.

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PREFACE.

THE object of the following pages is not to propound any new hypothesis, but simply to explain and discuss theories which have been supported by well-known astronomers and other men of science. Hypotheses which are merely paradoxes will of course not be considered. As these are generally advanced by persons possessing no scientific knowledge, and apparently incapable of grasping the simplest principles of mathematical astronomy, their views are, as a rule, unworthy of serious thought or refutation.

The latest results respecting the distribution of stars and nebulæ, their relative motions, and the physical constitution of the heavenly bodies, will be given; and it is hoped that the work will prove of interest to the general reader as well as to the student of astronomy.

With reference to the origin of matter itself, the Visible Universe may possibly have been evolved from a spiritual Unseen extending throughout a past eternity, as the authors of *The Unseen Universe* maintain; but in the following pages I only propose to deal with the construc-

tion of the Universe *as we see it*, and its probable development from pre-existent matter. There are, however, two points in which the Universe, as we know it, apparently comes into contact with the Unseen. These are the mysterious force of gravitation and the luminiferous ether. That gravity is an amazing mystery no thoughtful person will deny. Various theories have been advanced to explain the method of its action, but none of them are really satisfactory solutions of the problem. Various views of the constitution of the ether have also been propounded, and its very existence is disputed by some writers. There may possibly be a close connection between the two mysteries, and should the time ever come when we shall thoroughly understand the constitution of this, at present, inconceivable fluid, such knowledge may not improbably lead us to a solution of the great mystery of gravitation.

The first four chapters contain a popular account of the theories which have been advanced to explain the evolution of the Solar System and the origin of the Sun's heat. The fifth and sixth chapters give some account of the luminiferous ether and the supposed constitution of matter. The seventh chapter deals with celestial chemistry. The remaining chapters describe the construction of the sidereal heavens and the various theories respecting the constitution of the Universe which have been advanced by eminent astronomers.

September, 1892. J. E. G.

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*** *My best thanks are due to the* EARL OF ROSSE, MR. BARNARD *of the Lick Observatory,* DR. BOEDDICKER, M. M. HENRY *of the Paris Observatory, and* DR. ISAAC ROBERTS, *for their kind permission to reproduce some of the illustrations given.*

J. E. G

THE VISIBLE UNIVERSE.

CHAPTER I.

THE NEBULAR HYPOTHESIS.[1]

"This world was once a fluid haze of light,
Till towards the centre set the starry tides,
And eddied into suns, that wheeling cast
The planets."

TENNYSON.[2]

IN the year 1755 the famous German philosopher Immanuel Kant advanced a theory respecting the origin of the universe in a work entitled *Allgemeine Naturgeschichte und Theorie des Himmels.* This work is divided into two parts. In the first part Kant considers the constitution of the stellar heavens and the Milky Way, and reproduces views previously propounded by Thomas Wright, of Durham, and published in 1750 (see Chapter XIII.). In the second part he treats of the origin of the Solar System, and it is this portion of his work which has an especial bearing on the subject of the present chapter.

[1] For most of the details contained in the present chapter I am indebted to M. Wolf's interesting and valuable work *Les Hypothèses Cosmogoniques* (Paris, 1886).

[2] *The Princess.*

Kant considered that matter originally existed scattered through space, and that, by the force of gravitation, this matter was drawn together into isolated masses which now form the Sun and planets. In addition to the force of gravitation, acting according to the law of Newton, Kant supposes a repulsive force which acts only at very small distances, and especially when matter is reduced to an extreme state of subdivision. He supposes the masses of matter formed by gravitation to have been originally in repose, but imagines that a motion of rotation might have been set up by internal movements among the component particles. The denser particles situated near the centre of the primitive mass would attract the lighter particles lying near the surface. The latter in their fall towards the centre would be subject to deviations from a rectilinear path by the force of repulsion acting between the particles.

In this way he conceives that a vortex motion might be set up which would result in a motion of rotation of the entire mass. In one portion of this mass each particle would be eventually "maintained at a constant distance from the centre by an equilibrium between the centrifugal force and the force of the fall." But in the greater portion of the primitive mass the particles, reduced to rest by collisions, would fall directly to the centre and form a preponderating mass, which now constitutes the Sun. He supposes that the same action which formed the Sun continued to act on subordinate portions of the primitive mass, and that thus the planets were produced, the original motion of rotation causing them to revolve round the Sun in the same direction that they rotate on their axes.

According to Kant's theory, the mass and density of the

planets depend upon their distance from the Sun. The density of the original mass increased from its surface to its centre. The exterior planets would therefore be formed from lighter materials than the interior. But the greater the distance of a planet from the Sun, the larger would be the sphere from which it could draw in particles to increase its mass. The outer planets should therefore be larger than the interior. This is roughly but not rigidly true. The large planets, as a rule, lie on the exterior and the smaller on the interior of the planetary system. But Neptune and Uranus are each smaller than Saturn, and Saturn is smaller than Jupiter. Kant explains this fact in the case of Saturn, Jupiter, and Mars[1] by the influence of each planet on the sphere of action of its neighbours. Thus the size of Mars was ruled by the preponderating influence of the giant Jupiter, which in a similar way influenced the mass of Saturn. Mercury's small mass he attributes to the vicinity of the Sun, and also to that of Venus.

Supposing the Sun and planets to have been formed from the same materials, Kant concluded that the mean density of the planets should be the same as that of the Sun. Adopting the figures given by Buffon, he found the ratio of the density to be 64 to 65. Modern results show that this equality of density is only approximately true. The near approach to identity is, however, interesting and suggestive, and Kant thought it formed a conclusive proof of the truth of his hypothesis.

According to Kant's theory, the satellites were formed

[1] Neptune and Uranus were, of course, not discovered till after Kant's time.

from the planets in the same way that the planets were produced from the primitive mass. They therefore revolve round their primaries in the same direction that the planets revolve round the Sun. M. Wolf, however, points out that from the rotation assigned by Kant to the solar nebula it would result that the particles farther from the Sun would have a smaller linear velocity than those that are nearer, and that consequently the rotation of a planet, and the revolution of its satellites, should be contrary to the observed direction of motion. M. Zöllner also admits that this motion should be—according to Kant's supposition—retrograde instead of direct.

It also follows from Kant's theory that the larger planets should alone have satellites. The moons of Mars are therefore opposed to Kant's hypothesis.

According to Kant's view, comets have had the same origin as the planets, and differ from them—astronomically speaking—only in the eccentricity and inclination of their orbits. They were formed, he thought, at a great distance from the Sun, in regions of feeble attraction and highly rarified matter. Their movements should be generally—like the planets—direct. He attempts to show, however, that they might possibly be retrograde in some cases, but seems to think that the few comets with retrograde motion known in his day were either exceptions to the general rule, or that the apparent motions were due to errors of observation.

Kant devotes a chapter of his work to a consideration of the origin of Saturn's rings. He thinks that Saturn was originally a body analogous to the comets, and revolved in an orbit of high eccentricity. Approaching the vicinity of

the Sun, it became highly heated and surrounded by a vast atmosphere similar to a comet's tail. Gradually the orbit became nearly circular, and the planet cooling down its atmosphere condensed into the system of rings we now see surrounding it. This formation of a ring from a planetary atmosphere was due, he thought, to the rotation of Saturn on its axis, and on this hypothesis Kant computes the planet's period of rotation (unknown in his time) at 6h. 23m. 53s., a result which differs rather widely from Professor Asaph Hall's observed period of 10h. 14m. 24s. He also showed how the flattening at the poles of Saturn's globe might be computed. Kant conjectured that the earth was originally surrounded by a ring, and that the deluge recorded in Genesis was due to the rupture of this ring and its downfall on the earth!

Kant's theory seems to have been unknown to Laplace. It has one point in common with Laplace's Nebular Hypothesis, namely, that it supposes the Solar System to have been evolved from a primitive nebulous mass; and to Kant seems certainly due the credit of having first advanced this bold hypothesis. Kant's primitive mass, however, differs essentially from Laplace's nebula, both in its properties and the character of its motion, and Kant's views are often in direct opposition to those of his illustrious successor.

Laplace's Nebular Hypothesis was originally propounded in the first edition of his work *Exposition du Système du Monde*, published in the year 1796. The theory was further advanced in the third edition of the same work, which appeared in 1808, and was completed in subsequent editions, the sixth and last of which was published in 1836,

nine years after the author's death. Although presented by Laplace "avec la défiance que doit inspirer tout ce qui n'est point un résultat de l'observation ou du calcul," it should be remembered that the hypothesis was the result of long and careful consideration by one of the most brilliant mathematicians which the world has ever produced.

The fundamental idea in Laplace's theory was that the Sun's atmosphere originally extended beyond the orbit of all the planets, and that it has gradually shrunk to its present limits,[1] abandoning at intervals masses of matter which afterwards consolidated into planets. Laplace seems to have adopted Sir W. Herschel's view of the formation of stars from planetary nebulæ, or rather from a nebula with a condensed centre. This he considered to have been the original condition of the Sun, but he supposed that the formation of the planetary system did not commence until the condensation of the original nebula was far advanced and a true nucleus had been formed.

Laplace's original nebula differed essentially from Kant's primitive mass. The latter was supposed to consist of separate particles revolving round a centre, according to the law of equal areas in equal times, whereas Laplace's nebula consisted of an elastic gas, the different layers of which rotated with the same angular velocity. This nebula extended to a point at which the centrifugal force due to its motion of rotation was exactly balanced by gravity acting towards the centre. Its form was that of an ellipsoid, of which the ellipticity or flattening at the poles

[1] Laplace's words are: "L'atmosphère du Soleil s'est primitivement étendue au delà des orbes de toutes les planètes, et qu'elle s'est resserrée successivement jusqu'à ses limites actuelles."

could not exceed $\frac{1}{3}$. Laplace does not assign any reason for the existence of rotation in his primitive nebula, and seems to have assumed that the rotation was a property with which it was originally endowed.[1] He supposes the planets to have been formed from rings detached by the force of the rotation, combined with the cooling and consequent shrinkage of the parent mass. These rings would continue to condense, and would eventually form a solid or liquid ring. But this would be an extremely rare case, and we have only one example of such a phenomenon in the Solar System, namely, the rings of Saturn.

The rings would in most cases break up into separate masses of a spherical form, having a rotation on their axes in the same direction as that of their revolution round the central nucleus. If one of these masses was of much greater size than the others, it would in the course of time gather together the smaller masses by the force of its attraction, thus forming a spherical gaseous mass revolving round the Sun or central nucleus. These masses condensing would form planets, and would in a similar way detach rings forming satellites revolving round their primary in the same direction that the planets revolve round the Sun.

Laplace's hypothesis explains satisfactorily the following facts connected with the planetary system: (1) the approximate coincidence of the planes of the planetary orbits with the plane of the Sun's equator; (2) the small eccentricity of the orbits, which originally were probably circular; (3) the direction of revolution of the planets round the Sun and their rotation on their axes; also the direc-

[1] See Chapters on "Stellar Evolution" and "The Fuel of the Sun."

tion of motion of the satellites round their primaries. These motions are all performed from right to left, or contrary to the motion of the hands of a clock.

When Laplace's theory was published only four small planets were known between Jupiter and Saturn. Since that time over three hundred more have been discovered, and all these revolve round the Sun in the same direction as the larger planets. The probability against such an arrangement being merely the result of chance is very great indeed, and the facts have always been considered to be greatly in favour of Laplace's hypothesis. The discovery of the satellites of Uranus and Neptune—which have a retrograde motion—has however revealed two exceptions to the general rule. Laplace seems to have believed that the motion of the Uranian satellites was—like those of the other planets—direct. Neptune was discovered since his death. In both cases the motion is now known to be certainly retrograde. This retrograde motion is of course in direct opposition to Laplace's hypothesis, and to overcome the difficulty a theory to explain it has been advanced by M. Faye,[1] who thinks that Laplace's theory is untenable. This explanation will be considered in the next chapter.

Contrary to Kant's views, Laplace considered that comets were originally strangers to the planetary system.

Comets of short period have usually direct motion and small inclinations, which agrees with Kant's theory, whereas parabolic comets, or comets with very long periods, agree better with Laplace's hypothesis. Mr. Monck points out that "retrograde comets of comparatively short period" (such as that connected with the November Leonid meteors) "would

[1] See M. Faye's *Sur l'Origine du Monde* (1885), p. 156.

be inconsistent with Laplace's hypothesis unless they were wanderers from space captured by some planet."

Some modifications and additions have been proposed to Laplace's original hypothesis. Several objections have also been raised to it. I will consider the modifications first and the objections afterwards, as is done by M. C. Wolf in his interesting and valuable work *Les Hypothèses Cosmogoniques* (1886), to which I am indebted for most of the details given in the present chapter.

The mechanical theory of the Sun's heat advanced in recent years by Helmholtz seems at first sight to lend support to the Nebular Hypothesis.[1] This theory, which is now very generally accepted by astronomers, supposes the solar heat to be due to the contraction of its mass caused by gravitation, and suggests that in former ages the Sun was of vastly larger size than it is at present, and possibly extended at one time beyond the orbit of Neptune. But on this theory the probable past duration of the Sun's heat can be computed, and this duration of solar activity does not meet the demands of geologists,[2] unless we admit that geological forces acted with much greater energy in former ages than they do at present.

Professor Newcomb has suggested a modification in the supposed formation of the rings detached from the original nebula. He considers that in its original state the primitive nebula was of a form nearly spherical. As it contracted it would gradually assume the shape of a flattened spheroid, and afterwards that of a flat and thin disk. From this disk rings would separate, which would con-

[1] See Chapter on "The Fuel of the Sun."

[2] See Chapter on "Stellar Evolution."

solidate into planets, as Laplace supposed.[1] Professor Kirkwood, however, considers that the transformation of the original nebulous mass into a disk or close system of rings would "fail to account for the formation of the solar system as it actually exists."[2] He has also shown that the rings abandoned by the original nebulous mass might have been formed simultaneously and not at long intervals. On this view of the matter the larger planets—Jupiter, Saturn, Uranus, and Neptune—would take longer to cool down and would be less advanced in their life-history than the others; and this agrees well with the view—ably supported by the late Mr. Proctor—that these giant planets are still in a highly heated condition, and have not yet sufficiently cooled down to form the abode of living creatures.

Let us now consider the principal objections which have been raised to the Nebular Hypothesis. I will take them in the order in which they are discussed by M. Wolf in the work already referred to. Some of these objections were anticipated and partially met by Laplace himself.

1. It has been objected that the formation of such rings as Laplace supposes is impossible. "Supposing the original nebulous mass to have been homogeneous in structure and to remain so during its contraction, its period of rotation, at first excessively slow, would diminish, according to the law of areas, as the square of the radius."[3] If when it extended to the orbit of Neptune it had a period of rotation equal to Neptune's period of revolution round the Sun, namely, 164·6 years, this period would be reduced to 67

[1] Newcomb's *Popular Astronomy*, p. 498 (edition of 1878).
[2] *The Observatory*, May 1880, p. 410.
[3] *Les Hypothèses Cosmogoniques*, p. 35.

years when the nebula had shrunk to the orbit of Uranus, to 16·7 years at the orbit of Saturn, and to 4·94 years at the orbit of Jupiter.[1] This period would be reduced to only 0·0014 of a day for the radius of the Sun. These figures of course differ widely from the actual periods of revolution of the planets inside Neptune's orbit.

The objection seems to have been anticipated by Laplace, for he supposed that at the centre of the original nebulous mass there existed—even in its earliest stage—a nucleus of comparatively considerable density, and that the friction between this central globe and the surrounding nebulous atmosphere, and the friction between the nebulous layers of this atmosphere, would check the increasing speed of rotation as it contracted. Trowbridge considers that when the ring from which Neptune was afterwards formed was abandoned, probably more than one half the mass of the original nebula was within the earth's orbit, and that the greater portion of this half was even within the orbit of Mercury. It seems therefore inadmissible to assume that the nebulous mass remained homogeneous in density during its contraction, as this would not be consistent with Laplace's original hypothesis.

But it has been further objected that after the Neptunian ring had been abandoned the nebula must have contracted "without further loss of matter" to the orbit of Uranus. How did this state of equilibrium exist for so long a period? and what gave rise to the *sudden* rupture which then took place? Kirkwood points out that the equilibrium once disturbed could not be re-established, and that consequently small gaseous masses would be constantly abandoned which

[1] *The Observatory*, May 1880, p. 411.

would form small bodies and not large planets like Uranus, Saturn, and Jupiter. As Miss Clarke says, "Each wisp of nebula, as it found itself unduly hurried, would have declared its independence, and set about revolving and condensing on its own account. The result would have been a meteoric, not a planetary system."

M. Roche, however, has shown by an ingenious and original investigation[1] that if we assume with Laplace that the original nebula had a considerable central condensation, rings would be abandoned and planets formed at distances represented well by Bode's law.

2. It has been objected that, even admitting the formation of such rings as Laplace supposes, the subsequent formation of large planets from these rings would be impossible. Laplace supposed that when a ring was abandoned it would break up into fragments, and "if one of them was sufficiently powerful to unite successively by its attraction all the others about its centre, the ring of vapours would be changed into one sole spheroidal mass, circulating about the Sun, with a motion of rotation in the same direction with that of revolution."

With reference to this point Professor Kirkwood says: "In regard to the mutual attraction here referred to, it may be remarked that two parts of the Neptunian ring on opposite sides of the Sun could produce no sensible perturbation of each other's motion. If, moreover, the fragments of any ring were distributed around the orbit with approximate uniformity, their mutually disturbing effects would

[1] *Essai sur la Constitution du Système Solaire* (Montpellier, 1873). The details of M. Roche's investigation are difficult and not suitable for reproduction in these pages.

nearly destroy each other. That this state of things should have obtained in the case of some of the eight principal planets is extremely probable. The theory, therefore, of planetary aggregation by the attraction between different parts of the rings, requires an indefinite antiquity of the solar system.

"Let us suppose, then, that the planet-forming process was due to the different velocities of the fragments into which a ring had been broken up. Take, for example, the ring which was transformed into Neptune. Let us assume that two fragments, A and B, differed in longitude by 180°, and that the mean distance of the centre of gravity of A from the Sun's centre exceeded that of B by 1000 miles. It is then easy to show that the corresponding difference of their angular velocities would not bring them together around the same nucleus in 150 millions of years. But even after *all* the fragments had thus been collected, other millions of years—assuming with Laplace that the united mass was still in the gaseous form—would be required for the process of condensation. The supposition we have made is not an extravagant one. In Laplace's cosmogony, therefore, hundreds of millions of years are involved in the separate history of a single planet. Is so great an implied age of the solar system admissible?"[1]

The objection is evidently a formidable one, but here again M. Roche comes to the aid of the Nebular Hypothesis, and shows that the formation of planets from rings of nebulous matter *would* be possible under certain conditions.[2]

[1] *The Observatory*, May 1880.

[2] *Mémoires de l'Académie de Montpelier*, 1849, 1850, 1851.

3. The objection has been raised that the planets formed from Laplace's rings should have a movement of retrograde rotation on their axes. This objection has been especially insisted on by M. Faye, whose views on the subject will be considered in the next chapter. In a memoir on the conditions of stability in Saturn's rings, M. Hirn shows however that a planet formed from a ring would have a *direct* rotation, and M. Roche's investigations seem to lead to the same conclusion. M. Wolf says: "Si je ne trompe, les remarques de M. Hirn et l'ingénieuse explication de la formation des anneaux que nous devons à M. Roche font disparaître entièrement l'objection de M. Faye." He further argues that even if we admit that the planetary nebula, formed from the condensation of a ring, had at first a retrograde rotation, this motion could not be sustained. For in the early period of its existence the incipient planet would be acted on by a powerful tidal action due to the attraction of the central mass, the result of which would be that the planet's rotation would be rendered direct. This result, he thinks, would be certainly true for the planets near the Sun, and would be doubtful only in the case of the external planets Uranus and Neptune, which have probably a retrograde rotation. It appears that this view of the matter was also presented by Laplace, who seems to have in this case, as in others, anticipated and dealt with most of the objections to his hypothesis.

4. Another objection which has been raised against the Nebular Hypothesis is that many of the satellites are at distances from their primary which are inconsistent with Laplace's theory. The Moon is a case in point. Its distance from the earth is greater than the radius which

the earth in its gaseous state would probably have had at the time of its formation from a nebulous ring. The inner satellite of Mars, Phobos, forms an exception in the opposite direction, its period of revolution being less than the planet's period of rotation on its axis. This point was briefly considered by Laplace with reference to the satellites of Jupiter. A more careful investigation of the subject was however necessary, and this has been undertaken by M. Roche.[1] He considers that the satellites were not formed during the early existence of the planetary nebula, and would not be formed until the nebula had—like the original solar nebula—considerably condensed at its centre, the mass being influenced in this case also by a strong tidal solar action.

It follows from M. Roche's investigation that the planets nearest to the Sun, being acted on by a stronger tide, would produce satellites more slowly and at a smaller distance from their primary than the others. The Moon, being an exception to this rule, must have been formed under peculiar conditions. As already stated, the Moon's comparatively great distance of 60 times the earth's radius is considered as an objection to Laplace's hypothesis. Calculation shows that when the gaseous mass, which afterwards consolidated and formed the earth, rotated in a period of 27·3 days (the Moon's period of revolution), the nebulous atmosphere would have extended only three-fourths of the distance which now separates the Moon from the earth.

M. Roche, however, points out[2] that in considering the

[1] *Mémoires de l'Académie de Montpelier*, vol. ix., 1877.
Mémoires de l'Académie de Montpelier, vol. ii., 1851, p. 399.

effect of tidal action on the nebulous mass we should—as in the case of oceanic tides—take into account, not the absolute attraction of the Sun, but the difference between the solar attraction exercised on a molecule of the atmosphere and that exerted on the centre of the earth. On this view of the matter he finds that the longer axis of the nebulous spheroid would, at the epoch referred to, be exactly 60 radii of the earth as it exists at present. This axis would, however, be always directed towards the Sun, the other axes at right angles to the major axis being shorter. M. Roche then concludes that the Moon had its origin, not in a ring, but in matter abandoned at the extremity of the longer axis at a time when the nucleus had sufficiently consolidated. Researches by M. Simon agree with those of M. Roche. The formation of internal rings in the nebulous mass which afterwards formed the planet Mars would account, on this hypothesis, for the formation of Phobos, which seems to have been of relatively recent origin compared with the age of our Moon.

With reference to the ring system of Saturn, M. Roche has shown that the rings have not consolidated into a satellite because that, within a distance of 2·44 radii of the planet, the attraction of the planet would produce on a nebulous satellite of the same density tides which would be inconsistent with a permanent form of equilibrium. The satellite would be shattered and fall in pieces on the surface of the planet. M. Hirn's conclusions agree with those of M. Roche; and the theory that Saturn's rings consist of a crowd of small satellites each revolving in its own orbit round the planet seems to be consistent with these views. Although the entire ring system lies within Roche's

limiting distance of 2·44 radii of the planet's globe, the particles composing it may be so small and of such rigidity as to resist the disruptive action of Saturn's attraction.

That a nebulous ring might, under certain conditions, form a number of small planets instead of a single large one is evidently possible, for an example of such a result is visible in the system of small planets revolving round the Sun between the orbits of Mars and Jupiter. Kirkwood and Proctor have shown that the orbits of these minor planets are divided into zones separated by intervals analogous to the divisions in Saturn's ring system. These divisions in the "asteroid" system have been caused by the disturbing action of Jupiter, in the same way that the Cassini division in Saturn's rings is due to perturbations produced by the interior satellites.

5. Another objection to the Nebular Hypothesis is that the satellites of Uranus and Neptune revolve round these planets in a retrograde direction. The question of the rotation of these planets on their axis has not yet been decided by observation, but it seems highly probable from analogy that they rotate in the same direction that the satellites revolve round their primary. M. Faye considers this objection so important and so fatal to Laplace's theory that he has formulated a new theory of planetary evolution, which will be considered in the next chapter. It will therefore be interesting to examine the objection in detail, and inquire whether it is really so formidable as M. Faye supposes.

Laplace himself was not ignorant of the fact that there was something exceptional in the motion of the satellites of Uranus (Neptune was not discovered till after Laplace's

death). But owing to the fact that the plane of the satellite orbits lies nearly at right angles to the plane of the planet's orbit, Laplace may have concluded—as M. Faye suggests[1]—that the motion of the satellites was really direct. However this may be, it seems probable that, according to the Nebular Hypothesis, the planets when first formed should have had their axes of rotation at right angles to the planes of their orbits, or the general plane of rotation of the original nebula. How, then, was the axis of Uranus brought so nearly into coincidence with the plane of the planet's orbit? The answer to this question would involve the general one, namely, Why are the equators of all the planets more or less inclined to their orbit planes? As far as is known the planet Jupiter is the only one[2] whose equator plane nearly coincides with the plane of its orbit, the angle between the two planes being about 3°.

With reference to these inclinations Laplace says: "On conçoit que les variétés sans nombre, qui ont dû exister dans la température et la densité des diverses parties de ces grandes masses, ont produit les excentricités de leurs orbites, et les déviations de leurs mouvements du plan de cet équateur." With reference to the inclination of the planetary orbits to the general plane of the Solar System, M. Trowbridge points out that if we suppose a larger mass to be detached from one side of the equator of the original rotating spheroid than from the other side, a disturbance of

[1] *Sur l'Origine du Monde*, p. 156.

[2] If, however, Schiaparelli's observations of Mercury are correct, the axis of rotation lies nearly at right angles to the plane of the planet's orbit, and Jupiter would not be the only exception.

equilibrium would result which would change slightly the direction of its axis of rotation, and that a change of this kind might have been produced when each ring was abandoned.

Le Verrier and Tisserand have shown that the influence of perturbations between the planets would also tend to increase the inclination of their orbit planes. This influence would have a great effect in the case of a small mass acted on by other masses considerably larger. Of this we have examples in the case of Pallas and some of the other minor planets.

The question of the inclination of the planetary equators to the planes of their orbits has been considered by M. Simon and Professor G. H. Darwin. The former has shown that if we suppose the earth to have been formed by the consolidation of a series of rings, the inclination of these rings, acted on by the attraction of the Sun or central nucleus, would have increased in time. This might apply to the planets nearest the Sun, but at the great distance of Saturn and Uranus the disturbing action of the Sun would seem insufficient to produce the observed results.

Professor Darwin has considered the question from a totally different standpoint. Supposing the planet to be in the state of a viscous spheroid which, according to Sir William Thomson, is subject to the same laws as a nebulous mass, he concludes that every increase in the equatorial protuberance would tend to increase the inclination of the equator to the plane of the planet's orbit. In the case of the earth he finds that the obliquity of the equator would have had nearly the same value as it has at present when the earth, in its gaseous state, extended as far as the

Moon's orbit. In the case of the more distant planets he is obliged to invoke the aid of the satellites. M. Wolf, however, thinks that Professor Darwin's views are still beset with many difficulties. They do not satisfactorily explain why the Moon's orbit plane is inclined only 5° to the plane of the ecliptic, nor how it is that most of Saturn's satellites revolve in the plane of the planet's equator.

Reviewing all the objections which have been raised against the Nebular Hypothesis, M. Wolf considers that most of them have been satisfactorily answered. He thinks that only two doubtful points remain, namely, (1) How the gaseous matter of the ring abandoned by the original nebulous mass was consolidated into a planet of large size; and (2) How the inclinations of the planetary equators and the orbits of the satellites on the planes of the planets' orbits have been produced. These difficulties are, however, not peculiar to Laplace's views, but are common to all theories which suppose the planetary system to have been evolved from a rotating nebulous mass.

How the original nebulous mass acquired its motion of rotation Laplace did not attempt to explain. If we imagine the nebula to have been formed by the impact of two solid bodies, an oblique collision would give rise to the required rotation (see Chapter on "The Fuel of the Sun"). The late Mr. Jacob Ennis, however, concludes that the rotation was due to the action of gravitation alone. He says:—

"My own discoveries have at length placed the nebular theory on a firm mathematical foundation. The chief of them are these: (1) That gravity must necessarily and unavoidably produce rotation as well as rotundity in all nebulæ; (2) That gravity may increase that rotation so rapidly as to afford a centrifugal equal to the centripetal force; (3) That in nearly all nebulæ forming solar and planetary

systems rotation must begin on the surface, and hence must be retarded by the unrotating or slowly rotating interior. This retardation accounts for a vast number of most important stellar phenomena. Nothing in my calculations opposes the doctrine of equal areas swept by the *radius vector* in equal times. If the nebulæ forming our solar system and extending at first halfway to the nearest fixed star had originally a rotation velocity of only the one-third of a mile per hour, then its *radius vector* would have swept over an area equal to that of Mercury, whose orbital velocity is 110,000 miles per hour.

To satisfy the law of equal areas described in equal times, Ennis finds that when the Sun was expanded to the orbit of Mercury the rotation velocity would be less than 56 miles per hour. At the earth's orbit it would be 22 miles per hour, and at the orbit of Neptune less than *one* mile per hour. But the Sun's present rotation velocity is about 4500 miles per hour. The velocity has therefore increased instead of diminished, as should have occurred according to some supporters of the Nebular Hypothesis. Ennis explains this increased velocity of rotation in the following way :—

"In the course of contraction the *radius vector* of the nebulous Sun, instead of sweeping over equal areas in equal times, swept in fact over smaller and smaller areas at the distance of every succeeding planet. This would have stood as a valid objection to the nebular theory. But happily I discovered that nebular rotation must necessarily begin, in nearly all cases, not at the centre of the nebula, as all previous writers had supposed, but on the surface. This surface rotation must of necessity be *retarded* by friction on the unrotating interior ; hence the *radius vector* must sweep over smaller and smaller areas in proportion to the amount of *retardation*. But in a general sense the principle of equal areas in equal times holds true ; because what is lost in velocity by the particles on the exterior is gained by those of the interior. The *sum* of the areas swept by the *radii vectores* of all the particles must be a constant quantity ; but practically these areas cannot be computed, because we do not know the densities of the several strata of the

nebula, and hence we do not know the positions of the particles, or the length of their *radii vectores*. Nevertheless on Professor Loomis's plan, and what *appears* to be the plan of Comte, Nichol, and others, the principle of equal areas in equal times must be followed out with a single *radius vector* extending from the Sun's centre to his surface; and then the absurdity of their statements becomes manifest."

Ennis thinks that gravity is "the force which in the beginning put all the heavens and the earth in motion." He finds that "the velocity of a fall from infinite space[1] to the orbit of a planet is to the orbital velocity of a planet as 100 to 70 very nearly," and says :—

"If the velocity of a fall from infinite space to any orbital velocity be as 100 to 70, then it may be objected that the force of gravity is too great to be the force which gave their velocities to the stars. To this it may be replied: (1) That no rotation of any nebula actually began off at infinite space: large contraction must have taken place before rotation began; (2) That rotation began generally on the exterior, and the velocity was *retarded* by friction on the interior. In the case of our solar system I have proved that this retardation between the orbits of Neptune and Uranus was one per cent. in a contraction of 250,000,000 miles in diameter of our nebulous Sun: so nearly does the actual velocity of Uranus agree with its velocity as due to the force of gravity."

Ennis thinks that the "long-drawn-out arms" of the primitive nebulous clouds would as they fell "come down obliquely, and these oblique falls would lead to rotation." At first there would only be a rotation on the surface of the nebulous mass, but

"The amount of rotation would be continually increasing, on account of the continual contraction of the nebulous globe. The contraction of the globe would increase the amount and velocity of rotation in this way: Every particle of a globe, as it went forward, went also downwards towards the centre by contraction. They would

[1] This is known as the "parabolic velocity."

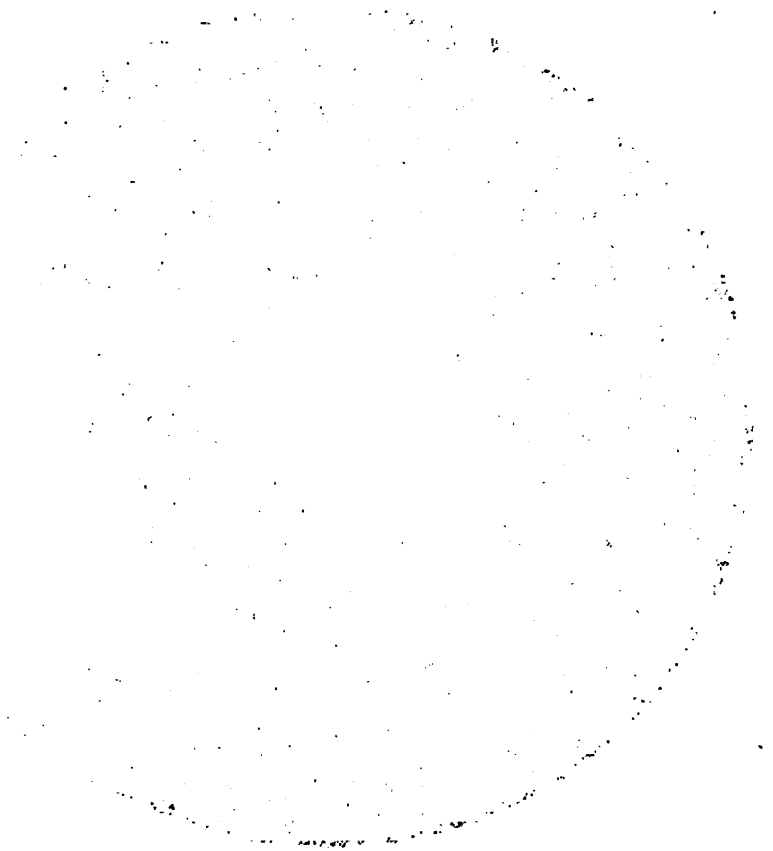

PLATE I.

[illegible] the Spiral Nebula 51 M[illegible] in Cane-Venatici
R.A. 13h. 25m., Dec. N. 47 [illegible].

[illegible] D.Sc., F.R.S. Exposure of 4 hours on April 2[illegible], 18[illegible]
(From the [illegible] photograph.)

[illegible] of the particles [illegible] Nevertheless or Professor [illegible] of Comte, Nichol [illegible] be followed [illegible] from the [illegible] of [illegible]

[illegible] is [illegible] gravity is "the force which [illegible] and the earth [illegible] velocity of a fall from infinite space [illegible] is to the orbital velocity of [illegible] 100 to [illegible]," and says:—

"[illegible] from infinite space to any [illegible] may [illegible] object [illegible] that [illegible] of gravity [illegible] the [illegible] (1) That [illegible] (2) That [illegible] generally [illegible] on the [illegible] proved that this [illegible] of Neptune and [illegible] 1000 [illegible] of [illegible] or Uranus [illegible]

[illegible] the [illegible] would as they fell [illegible] would lead to [illegible] would only be a [illegible]

[illegible] would [illegible]

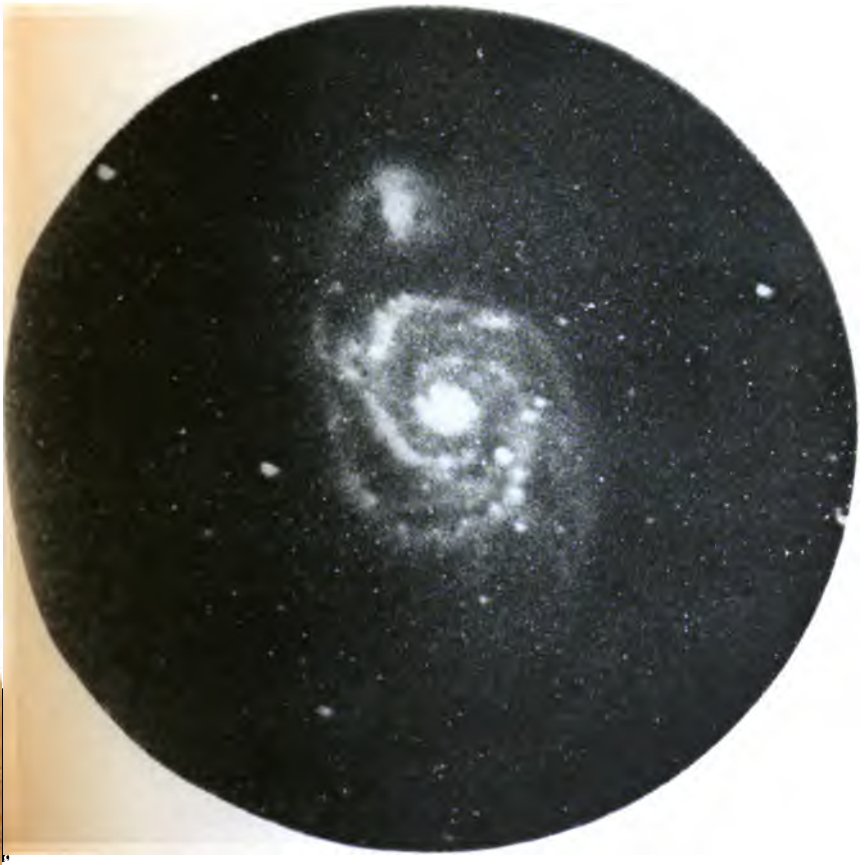

PLATE I.

Photograph of the Spiral Nebula 51 Messier (in Canes Venatici).
R.A. 13h. 25m., Dec. N. 47° 45′.

By ISAAC ROBERTS, D.Sc., F.R.S. Exposure of 4 hours on April 29, 1889.
(From the original photograph.)

all, therefore, take the direction of an inclined plane, and go down all the while faster and faster, according to the law of descent down an inclined plane."

With reference to the planetary velocities and the velocity of the Sun's rotation on its axis he says :—

"All nebulæ, solar and planetary, rotated with constantly *increasing* velocities. Hence each planet and satellite has a greater velocity than its next outer neighbour. But after the parting of the last equatorial ring, then the Sun and also the planets began to rotate with *decreasing* velocities. Therefore the equatorial velocity of the Sun is now less than the orbital velocities of the planets, and the equatorial velocities of the planets are less than the orbital velocities of the inner satellites. The cause of this is found to be the principle of retardation."

The Nebular Theory was of course purely an hypothesis, and was not originally supported by any facts derived from direct observation. Recent photographs of spiral nebulæ,[1] and especially of the great nebula in Andromeda, are considered by many to afford strong evidence in favour of the correctness of Laplace's hypothesis. In the Andromeda nebula we seem to see nebulous rings in actual process of formation (see Frontispiece), rings apparently in rotation round a strongly condensed central nucleus, and which, in the course of ages, will probably condense into planets revolving round a central sun. Judging from its great apparent size, and its probably vast distance from the earth, the system formed from this nebula will evidently be one of gigantic dimensions,[2] but probably the general principle of the process would be the same for smaller systems. Referring to these photographs Mr. Herbert Spencer says: "Practically demonstrated as this process now is, we may

[1] See Plate I.

[2] See *Journal of the British Astronomical Association*, vol. i., p. 483.

say that the doctrine of a nebular genesis passes from the region of hypothesis into the region of established truth."

The Nebular Hypothesis is supposed by some to be opposed to revealed religion. But this is not the case. On the contrary, it should tend to exalt our ideas of the Creator. As Herbert Spencer says, "Creation by manufacture is a much lower thing than creation by evolution. A man can put together a machine; but he cannot make a machine develop itself. That our harmonious universe once existed potentially as formless diffused matter, and has slowly grown into its present organized state, is a far more astonishing fact than would have been its formation after the artificial method vulgarly supposed. Those who hold it legitimate to argue from phenomena to noumena, may rightly contend that the Nebular Hypothesis implies a First Cause as much transcending 'the mechanical God of Paley,' as this does the fetish of a savage."[1]

[1] *Westminster Review*, July 1858.

CHAPTER II.

M. FAYE'S THEORY.

M. FAYE'S views on the Nebular Hypothesis are contained in a very interesting work *Sur l'Origine du Monde*, the second edition of which was published in Paris in the year 1885. He first considers the account of the Creation as given in the Book of Genesis. He then reviews, in a series of chapters, the ideas entertained by the ancient writers, Plato, Aristotle, Cicero, Lucretius, Virgil, and Ovid,—views of course very vague, and now possessing merely an historical interest. In the third part of the work he discusses the views of Descartes, Newton, Kant, and Laplace. The theories of Kant and Laplace have been considered in the first chapter of the present volume. In the fourth part he gives a summary of our present knowledge of the nebulæ and clusters, double, binary, and variable stars, and the Milky Way, with reference to which he says: "On trouvera que la Voie lactée offre plus d'analogie avec un vaste anneau en train de se décomposer en lambeaux qu'avec une couche plate et homogène d'étoiles et de nébuleuses."[1] With this view I fully concur, and hope in the pages of this volume to adduce strong evidence in favour of the truth of M. Faye's opinion. He then

[1] *Sur l'Origine du Monde*, Second Edition, p. 214.

considers the question of the Sun's constitution, and the source of its light and heat, a subject which will be discussed in a subsequent chapter.[1]

In the thirteenth chapter of his work M. Faye proceeds to propound his views on the evolution of the Solar System from materials originally scattered through space. He points out that we cannot endow a sun—as (he states) Laplace did—with an unlimited supply of heat, the heat expended by any sun and the heat it still possesses depending upon its mass and volume. This is, of course, true, but it should be remembered that the great principle of the Conservation of Energy has only been discovered in recent years and was unknown in Laplace's time.

M. Faye estimates that the white and yellowish stars constitute about 95 per cent. of the stellar hosts. He considers that the red and variable stars are suns on the eve of extinction, but this is a conclusion which is far from being established with certainty.

He points out that the motions of the primitive nebula from which suns and systems were formed are indicated by the Sun's motion in space, and that the rotation of the original mass survives in the revolution of the binary stars round the centre of gravity of their components.

The chief difficulty experienced in imagining the existence of a primitive nebulous mass lies in the fact that the diffusion of matter through space seems opposed to the law of universal gravitation, a force which tends to concentrate all matter into one mass. Neither Kant nor Laplace attempted to explain how the primitive nebula originated, and to overcome this difficulty the late Dr.

[1] See Chapter on "The Fuel of the Sun."

Croll proposed his Impact Theory of Stellar Evolution, which will be considered in the next chapter.

But admitting the existence of a primitive nebula, we still find a difficulty in understanding how such diverse forms as single stars, double, triple, and multiple stars, solar systems and globular clusters, could all have been formed by a single process of condensation from similar masses of nebulous matter.

M. Faye proceeds to consider each of these cases separately. First, with reference to isolated single stars. Imagine a spherical homogeneous mass, without internal motions of any kind. The component molecules would gravitate towards the centre. The mass would consolidate regularly, preserving its homogeneity, and would eventually form an incandescent motionless sphere, without planets, satellites, or rotation on an axis. M. Faye considers, and I think correctly, that the heavens do not contain many examples of this species of star.

If, on the contrary, the original mass had internal motions, the result would probably be that portions of the nebulous matter would fall towards the centre, not in straight lines, but in concentric ellipses, revolving in equal periods round a common centre of gravity. Thus M. Faye thinks a globular cluster would be formed.

He considers, however, that the most general case would be that of a primitive nebulous mass, *not* homogeneous, and animated with vortices which, according to circumstances, due to the mass and distribution of portions of different densities, would cause the formation of two, three, or more globes, revolving round their common centre of gravity. Thus would be formed binary, triple, and multiple stars.

He gives what he calls a complete table of binary stars, but recent calculations have now more than doubled the number of binary systems included in his list. As an example of a multiple star he mentions θ Orionis—the so-called "trapezium" of telescopists—but recent measures by Mr. Burnham show that there is no relative motion in the components of this group, and it would seem very doubtful that they really form a physical system.[1] We have perhaps a few examples of quadruple systems, but of multiple systems (of more than four stars) I do not know of a single well-established case.

M. Faye then proceeds to a consideration of the formation of the Solar System. He points out that if Jupiter and Saturn were still in a state of incandescence, the Sun seen from α Centauri would appear as a triple star. This is quite true; for if these large planets had the same intrinsic brightness as the Sun, the Sun would be about a hundred times—or five stellar magnitudes—brighter than Jupiter; and as the Sun would shine as a star of the second magnitude (or slightly brighter) as seen from α Centauri, Jupiter would be visible as a star of about the seventh magnitude, and Saturn slightly fainter. But it is very certain that with their *present* brightness these planets would be utterly invisible from α Centauri, even with the Lick telescope. Seen from the stars, therefore, our Sun would appear as a single star, and as such it must be considered when comparing it with its neighbouring suns in space.

[1] Mr. Burnham says: "A comparison of these measures with those made by Struve, Hall, and others show beyond question that the six principal stars are absolutely fixed with reference to each other, so far as any change is concerned which could be detected by observations covering more than half a century."—*Ast. Nach.*, No. 2930.

The Solar System differs also from the binary stars in the eccentricities of the planetary orbits, which, with the exception of Mercury and some of the minor planets, are very small, while the majority of the binary systems have orbits of large eccentricity. Although this difference is not of especial importance from a mechanical point of view, still, as the circle is merely a particular form of the ellipse, we should not expect the planetary orbits to approach, in so many cases, so closely to the circular form. M. Faye therefore considers that among the initial conditions of the primitive nebula we must seek for a cause which has prevented the planetary orbits from becoming elliptical, and has preserved them through all their changes in a nearly circular form.[1]

There is an essential difference between Faye's hypothesis and that of Laplace. Laplace supposed the primitive nebula to have had a considerable central condensation *before* the planet-forming rings began to be detached from the parent mass, the central nucleus afterwards condensing into the Sun, as we now see it. M. Faye's nebula, on the contrary, is supposed to have been homogeneous, without any central condensation. He describes it as "Amas chaotique homogène, à peu près spherique, au sein duquel règnent de lents mouvements tourbillonnaires affectant une partie seulement de la masse."

M. Faye thinks that the first result of a slow movement of rotation in the original spherical homogeneous mass would be the formation of concentric rings in the *interior* of the nebula, rings rotating in a single mass in the manner of a solid body round a centre at first void.[2] These rings

[1] *Sur l'Origine du Monde*, pp. 263, 264. [2] *Ibid* p. 266.

would then break up into separate portions, which would eventually consolidate into a single mass, as in Laplace's hypothesis. "The other particles having velocities either very great or very small would move in the same plane, describing ellipses concentric with the ring. If these ellipses are very elongated, the materials which compose them approach closely to the centre, where they would produce a progressive condensation."[1] . . . "They would thus form a central mass, to which would be added all the materials of the primitive vortices which are not arranged in regular rings."[2]

The molecules near the exterior of the ring would have a greater linear velocity than those on the interior, and the resulting planet would therefore have a rotation in the same direction as that of the ring from which it was formed. This, he thinks, would have occurred in the case of the planets nearer the Sun,[3] and at a time when the central force acted according to a law directly proportional to the distance from the centre. These planets, he thinks, would be formed first and before the central body had taken a regular form. On his view of the matter the earth was formed *before* the Sun, and—contrary to Laplace's hypothesis—the interior planets are older than Uranus and Neptune, which M. Faye supposes to have been formed from rings detached *after* the Sun had consolidated, and when the central force acted according to the law at present operating in the Solar System, namely, inversely as the square of the distance. In these outer rings the velocity of the external parts would be less than at the interior of

[1] *Sur l'Origine du Monde*, p. 265. [2] *Ibid.*, p. 268.
[3] Namely Jupiter and all the planets within its orbit.

the ring, and the resulting planet would, therefore, have a retrograde motion of rotation, or opposite to that of its revolution round the Sun. The satellites of these planets would also have a retrograde motion round their primary, as is found to be the case with the satellites of Uranus and Neptune.

In the case of Uranus he thinks that at the time of its formation the law of force was in a state of transition, and that the conflict between the two forces, namely, the force acting directly as the distance, and that acting inversely as the square of the distance, produced the high inclination of the planes of the Uranian satellites.[1] At the birth of Neptune the second law of force had become predominant, and hence the inclination of its satellite's orbit plane is not so great.

In the fourteenth chapter of his work M. Faye derives some support to his theory from geological considerations. He points out the discordance which exists between the long periods demanded by geology and biology, and the period indicated for the duration of the earth's existence by Laplace's hypothesis.[2] To reconcile this discrepancy, he considers it necessary to assume that the earth was formed *before* the Sun, and that it was consolidated from materials scattered through a space very much larger than its present dimensions. In its earliest ages the internal heat would have been sufficient, he thinks, to keep the surface waters warm, and even to partly evaporate them. He finds evidence in favour of this view in the existence of a tropical vegetation from the equator to the poles up to

[1] *Sur l'Origine du Monde*, p. 276, footnote.

[2] See Chapter on "Stellar Evolution."

the middle of the Secondary Period, a flora which must have flourished for millions of years.

To explain this early heat, Dr. Blandet has suggested that during the Primary Period the Sun had an apparent diameter of 47°, and that about this time the planet Venus was formed from the Sun's atmosphere. To this M. Faye replies that, according to Laplace's hypothesis, the planets were formed from an excessively rare atmosphere of the central mass, and not from the Sun's photosphere, as Dr. Blandet's theory implies. He further points out that with an apparent solar diameter of 47°, the necessary high temperature at the poles would be enormously increased in other regions of the earth's surface, so that a uniform temperature could not have existed. On M. Faye's hypothesis the earth's internal heat would, he thinks, have been —at the period in question—sufficient to keep the whole of its surface at a uniform temperature without the aid of a central sun. This he shows by calculation to be possible if we suppose the earth's crust to have been much thinner at that period than it is at present. Owing to the absence of a sun, the light at this period would be feeble; but he points out that the ferns which swarmed at that epoch flourish best in shade, and so do the insects which are found fossil in the rocks of these formations.[1]

Let us now consider the objections which have been raised against M. Faye's hypothesis.

1. With reference to the rings formed in the original nebula, M. Wolf points out that M. Faye does not explain satisfactorily how these rings were produced, or how large planets were formed from these rings, so that in this

[1] *Sur l'Origine du Monde*, p. 287.

particular M. Faye's theory is not more satisfactory than Laplace's original hypothesis. It might still be argued that the rings would probably break up into a number of *small* planets (see Chapter I.).

2. It has been shown in the preceding chapter that even on Laplace's hypothesis the rotation of a planet would be at first retrograde, but would afterwards become direct, owing to the strong tides produced by the central nucleus on the incipient planet. It would appear, therefore, that in M. Faye's system the direction of rotation of the interior planets—at first direct—should have been reversed by the action of the Sun when it had consolidated. To this M. Faye would perhaps reply that these planets had so far consolidated before the Sun was formed that tidal action would be inoperative.

M. Wolf further considers that M. Faye's division of the planets into two groups, one with a direct and the other with a retrograde motion of rotation, is contrary to a natural classification of the planets. He thinks that, from a consideration of their volumes, masses, and densities, the planets of the Solar System are clearly divided into two groups of four planets each, the groups being separated by the zone of minor planets.[1] There appears to be considerable force in this objection. The so-called "terrestrial planets" seem to form a group quite distinct from the larger or "giant planets."

M. Faye thinks that comets had their origin in the Solar System itself, but M. Wolf considers that the small number of known periodic comets is in favour of Laplace's theory that these bodies were drawn into the planetary

[1] *Les Hypothèses Cosmogoniques*, p. 72.

system, from outer space, by the force of the Sun's attraction.

M. Wolf finally concludes that, although many of the objections which have been advanced against Laplace's hypothesis may also, with equal force, be urged against that of M. Faye, still the theory of the latter astronomer explains more satisfactorily how the earth has had sufficient time to pass through the long periods indicated by geology. M. Faye's theory does not, however, admit of a longer period than twenty to thirty millions of years, while geologists and biologists demand at least a hundred millions for the duration of geological time. This conflict between astronomy and geology will be further considered in the next chapter.

CHAPTER III.

STELLAR EVOLUTION.

AN interesting work on this subject was published by the late Dr. Croll a short time before his decease.[1] Adopting Laplace's Nebular Hypothesis of the origin of the Solar System, Dr. Croll takes a step farther back in time, and proceeds to consider the probable origin of the supposed nebulous mass from which the planetary system was originally evolved. This nebulous mass he supposes to have been formed by the collision of two dark bodies, moving directly towards each other in space with a high velocity. A large proportion of the energy of motion thus arrested would of course be instantly converted into heat, which would be sufficient to transform into the gaseous state—at least on their surface—the broken fragments of the colliding bodies. We have a familiar example of motion thus converted into heat in the case of a bullet striking an iron target, the heat caused by the concussion being sufficient to raise the temperature of the bullet to a considerable degree. In this case, however, the target, being of so much greater mass than the bullet, absorbs most of the developed heat, and being at rest the amount of heat generated in the

[1] *Stellar Evolution and its Relations to Geological Time*, 1889.

bullet is not so great as if it met another bullet moving in the opposite direction.

The first thing which strikes us in considering Dr. Croll's theory is the enormous velocity assumed—476 miles a second! The greatest velocity we know of among the stars having large proper motions is that of Arcturus, which, according to a somewhat doubtful parallax, is speeding through space with the amazing velocity of 368 miles a second! and μ Cassiopeiæ, for which a minute parallax indicates a motion of 315 miles per second. The small star 1830 Groombridge—aptly termed by Professor Newcomb "a runaway star"—is, if the small parallax[1] found for it can be relied upon—moving with a velocity of 200 miles a second. This is the velocity at right angles to the line of sight. The star may of course have also a velocity *in* the line of sight, which would increase the above velocity. Since, however, the apparent proper motion of 1830 Groombridge is the maximum known to astronomers, we must look on Dr. Croll's assumed velocity as somewhat excessive.

The bodies coming into collision are assumed by Dr. Croll to be *dark* bodies, but of the existence of such dark bodies we have of course no *positive* evidence. He objects to the Nebular Hypothesis that it "begins in the middle of a process"; but the assumption of two dark bodies coming into collision leaves unexplained the origin of these bodies, and not alone the origin of their existence, but the origin of their rapid motion still remains a mystery. Dr. Croll, however, says: "The changes that now occur arose out of preceding changes, and these preceding changes out of changes still prior, and so on indefinitely back into the

[1] About one-tenth of a second of arc.

unknown past. This chain of causation—this succession of change, of consequent and antecedent—could not in this manner have extended back to infinity, or else the present stage of the universe's evolution ought to have been reached infinite ages ago. The evolution of things must therefore have had a beginning in time;"[1] evidently admitting the possibility of a creation *a nihilo*.

Assuming, however, the enormous velocity adopted by Dr. Croll, let us consider what the result of his hypothesis would be. He finds that for two bodies "each one-half of the mass of the Sun, moving directly towards each other," the result of the collision would be the development of an amount of heat which would satisfactorily account for the "present rate of the Sun's radiation" for a period of 50 millions of years. He computes that the gas developed at the moment of collision "would have a temperature of about 300,000,000 degrees" of the Centigrade thermometer, "or more than 140,000 times" that of the voltaic arc!

The first result of the collision would be the shattering of both bodies into a number of fragments, which by their subsequent collisions *inter se* would be reduced to smaller fragments, and these again, by the same process, into smaller fragments still, which, being acted on by the enormous heat of the generated gas, would gradually become gaseous also, so that "in the course of time the whole would assume the gaseous condition, and we should then have a perfect nebula—intensely hot, but not very luminous," occupying a space equal in volume to that of our Solar System. "As the temperature diminished, the nebulous mass would begin to condense, and ultimately, according

[1] *Stellar Evolution*, p. 110.

to the well-known nebular hypothesis, pass through all the different phases of rings, planets, and satellites, into our solar system as it now exists." To this hypothesis Dr. Croll gives the name of the "Impact Theory," to distinguish it from the Nebular Theory on the one hand, and from the meteoric and all other gravitation theories on the other.

With reference to the fragments produced by the supposed collision, Dr. Croll considers that it would be "highly improbable, if not impossible, that the whole of the fragments projected outwards with such velocity should be converted into the gaseous condition." Many of the smaller fragments would pass away into outer space, thus forming meteorites, which on this theory must be looked upon as "the offspring of sidereal masses, and not their parents, as Mr. Lockyer concludes." Comets also he considers to have had a similar origin. He admits, however, that some meteorites may have come from other systems.

A necessary assumption of Dr. Croll's theory is that the stars should be moving in all directions with various velocities "in perfectly straight lines, and not in definite orbits of any kind." He says: "So far as observation has yet determined all these conditions seem to be fulfilled." But are we justified in assuming that the stars are moving in straight lines? It is certainly true that the observed proper motions are *apparently* in a straight line, except in a few cases, like Sirius and Procyon, in the motion of which irregularities exist, the cause of which has only been partially explained. But should we therefore assume that the motion is really rectilinear? The small arc described in the comparatively limited number of years during which

observations of this kind have been made, leaves it, I think, an open question whether the motion is really in a straight line, or whether the short line of motion hitherto observed is merely the small arc of a gigantic orbit described round some, as yet unknown, centre of attraction.

In considering the motion of 1830 Groombridge, Dr. Croll assumes with Professor Newcomb "that the number of stars belonging to the universe amounts to 100,000,000,[1] and that these have on the average five times the mass of the Sun, and are spread out in a layer across which light requires 30,000 years to pass";[2] and Professor Newcomb concludes that "either the bodies which compose our universe are vastly more massive and numerous than telescopic examination seems to indicate, or 1830 Groombridge is a runaway star, flying on a boundless course through infinite space with such a momentum that the attraction of all the bodies in the universe can never stop it."

In speaking of "all the bodies of the universe," Professor Newcomb of course refers to the *visible* stars; but as Dr. Croll assumes it possible "that space is occupied by dark bodies far more numerous and massive than the luminous one which the telescope reveals," the motion of 1830 Groombridge may be, partly at least, due to the force of gravitation. As, however, Professor Newcomb computes that the total attractive power of the visible stars should be increased no less than sixty-four times to account for

[1] Professor Young also assumes 100,000,000 as the number of stars in the visible universe.

[2] If light suffers any extinction in the ether—as Struve supposed—then the distance of the faintest stars would be less and the light journey less.

the apparent velocity, it seems probable that a portion at least of the observed motion *is* due to initial velocity as the "Impact Theory" requires.

As examples of stars with large "proper motions," Dr. Croll mentions 1830 Groombridge, 61 Cygni, ϵ Indi, Lalande 21,258, Lalande 21,185, μ Cassiopeiæ, and Arcturus. To these may be added Lacaille 9352, a Southern star, which, with a proper motion of nearly 7 seconds of arc per annum, stands next in order to 1830 Groombridge; Gould 32,416, which has an annual motion of about 6 seconds; and the triple star 40(0^2) Eridani, of which the proper motion is 4·07 seconds. Other stars with considerable proper motions are: α Centauri, Lacaille 8760, Piazzi II. 123, Groombridge 34, Struve 2398, and β Hydri. As Professor Asaph Hall says, "Although the parallax of the star introduces considerable uncertainty" into the computed velocities, "yet we already know enough to be sure that these velocities are very great. Some of them are comparable to that of a comet in close proximity to our Sun. But in most cases there is no visible object near the one in motion to which we can ascribe an attractive force, acting according to the Newtonian law, which would produce the velocity observed unless we assume enormous masses."[1]

Dr. Croll lays stress on "the enormous *space* occupied by nebulæ." Some of these are certainly of vast proportions. The large planetary nebula in Ursa Major, known as "The Owl Nebula," has an apparent diameter which, if placed at the distance of the nearest fixed star, would imply a real diameter of about 200 times the Sun's

[1] Gould's *Astronomical Journal*, No. 177 (1888, August 8th).

distance from the earth! As its distance is, however, possibly far greater than that of *a* Centauri, its dimensions may be even still larger! Dr. Huggins finds the spectrum gaseous. It is possibly a solar system in its nebulous stage.

Dr. Croll derives some evidence in favour of his hypothesis from the relative densities of the planets composing the Solar System, the interior planets being the heaviest and the exterior the lightest. This is, however, only roughly true in a general way, for although Mercury is the heaviest planet of the Solar System, the lightest is not Neptune, but Saturn. In speaking of the satellites Dr. Croll falls into a serious error. He says: "The satellites of Jupiter, for example, have a density one-fifth of that of the planet, or about one twenty-fifth of that of the earth, showing that when the planet was rotating as a nebulous mass the more dense elements were in the central parts and the less dense at the outer rim, where the satellites were being formed." As a matter of fact, however, the density of Jupiter's first satellite (that nearest to the planet) is only a little less than that of Jupiter, that of Satellite IV. (the exterior one) is about equal to the density of the planet, while the densities of Satellites II. and III. are actually greater. This is a very different state of affairs to that supposed by Dr. Croll, the lightest being actually the nearest to the planet and the heaviest next in order.

According to Professor Lockyer the temperature of the original solar nebula was as high as that of the Sun at present. Dr. Croll, however, considers that "in some of its stages the nebula had a very much higher temperature than that now possessed by the Sun." This seems very

probable, for the cooling process which is now going on in the Sun has in all probability been in action since the planets solidified, or possibly from an earlier date; so that whatever temperature we may at present assign to the Sun, we must consider it to have been at a considerably higher temperature, say, twenty millions of years ago. As Dr. Croll points out, it is impossible that hydrogen or carbon could exist in the gaseous state in the cold of stellar space, unless possessed of considerable heat; and we know from the evidence of the spectroscope that hydrogen *does* exist in some of the gaseous nebulæ—notably in the great nebula in Orion. The feeble light emitted by these gaseous nebulæ is well accounted for by the fact that incandescent hydrogen, although possessing intense heat, has very little luminosity. Dr. Croll, however, ascribes the faint light of the nebulæ as chiefly due to the enormous space occupied by these bodies, and computes that their density does not probably exceed $\frac{1}{10,000,000}$, "that of hydrogen at ordinary temperature and pressure" (see Appendix, Note A). The *quantity* therefore of light would be very small, "resembling very much the electric light in a vacuum tube."

Dr. Croll considers that the phenomenon of Temporary Stars, such as those of 1572, 1604, and 1876, is due to the collision of a star with one of the dark bodies, or with a swarm of meteorites. The continuance of visibility was, however, of varying duration in the recorded examples of these wonderful objects; those of1572 and 1604 remaining bright for over a year, while the maximum brilliancy of those of 1866 and 1876 was only sustained for a few days or probably hours. His theory will also have to

account for the remarkable fact noted by Sir John Herschel, "that all stars of this kind on record, of which the places are distinctly indicated, have occurred, *without* exception, in or close upon the borders of the Milky Way, and that only within the *following* semicircle, the *preceding* having offered no examples of the kind." Since this was written, however, a notable exception to the rule occurred in the case of the temporary star of 1866, which so suddenly blazed out in Corona Borealis on the evening of May 12th of that year. But this star is itself an exception to the general rule, as it was not, correctly speaking, a new star, but an outburst of a small star previously *known* to astronomers. The temporary star of 1876, however, conformed to Herschel's rule, as it appeared in the Milky Way, near ρ Cygni.[1] The fact of this star having apparently faded into a small planetary nebula seems in favour of Dr. Croll's hypothesis.

Star clusters are explained by Dr. Croll on the supposition that in some cases the fragments resulting from the collision would be so "widely distributed through space" as to "prevent a nebula condensing into a single mass." The separate fragments would "gradually condense into separate stars, which would finally assume the conditions of a cluster." I presume that Dr. Croll refers more especially to the "globular" clusters than to those in which the components are more widely scattered, and certainly a satisfactory theory of the origin of these wonderful "balls of stars" is a desideratum in sidereal astronomy.

Sir William Thomson's conclusion that twelve millions

[1] The "new star" in Auriga of 1892 also appeared in the Milky Way, but in the *preceding* semicircle, contrary to Herschel's rule.

of years is the maximum period which can be allowed on the gravitation theory for the duration of the Sun's heat in past time,[1] and the apparent inadequacy of this period to meet the views of geologists as to the duration of life on the earth, also seems in favour of Dr. Croll's theory. It is objected, however, by Professor Kirkwood[2] that even if we admit that the Solar System originated in the collision, 800 millions of years ago, of two cold opaque bodies approaching each other in the same straight line with a velocity of 1700 miles per second, we must consider that only a *portion* of this period is represented by geological time. For, after the collision, ages must have elapsed before the planets had separated from the parent mass, and had sufficiently consolidated and cooled down to commence their geological history. When, however, the heated planet had cooled down to a temperature low enough to admit of the formation of an outer crust, its development into a life-bearing world would then be comparatively rapid. For Sir William Thomson has shown[3] that the internal heat could have no appreciable effect upon the temperature of the earth's surface 10,000 years after the formation of a definite crust. This follows from the fact that the heat-conducting power of the igneous rocks is very small. An illustration of this may be observed in lava recently ejected from a volcano, which may be walked on without danger, while a few feet below its surface it still remains in the molten state.

Trowbridge thinks that were the temperature of the Sun's surface "twice its present intensity the solar atmo-

[1] *Good Words*, April 1887. [2] *The Observatory*, April 1878.
[3] *Philosophical Magazine*, January 1863.

sphere would be expanded beyond the earth's orbit." Under these conditions all forms of life would of course be impossible on the surface of our globe. If therefore Trowbridge's result be correct, it would follow that the shrinkage of the Sun's mass from the diameter of the earth's orbit to its present size must have taken millions of years.

Professor Kirkwood is disposed to believe it more probable "that in former ages the stratification of the earth's crust proceeded more rapidly than at present." Geologists of the uniformitarian school do not seem willing to admit this hypothesis, and a short account of the evidence adduced by Dr. Croll as to the probable duration of geological time —a subject on which he was a well-known authority—may prove of interest to those of my readers who, like myself, take an interest in geological science.

Dr. Croll considers that the attempt "to compress the geological history of our globe into the narrow space allotted by the physicist is hopeless, as well as injurious to geological science." He proceeds to obtain "an accurate measure of absolute geological time" by a consideration of the result of subaerial denudation, and the method he adopts to ascertain the amount of this denudation is by an estimate of the quantity of sediment annually carried down to the sea by the great river systems. From a number of rivers on which experiments in this direction have been made he selects the Mississippi, as draining a country "which may be regarded as in every way resembling the average condition of the earth's surface." and from experiments made by Messrs. Humphreys and Abbott on the amount of sediment annually carried down to the sea by this river he

arrives at the conclusion that one foot in 6000 years may "be safely taken as the average rate of denudation of the whole surface of the globe." As, however, the area of the earth's water surface is three times that of the land this amount would be equivalent to a layer of three inches thick spread over the whole globe.

Assuming, then, that the average rate of denudation in past geological ages did not materially differ from what it is at present, and that the total quantity of stratified rock would, if uniformly spread over the whole globe, form a layer 1000 feet in thickness, we have a total period of 1000 multiplied by 6000, multiplied by 4, or 24 millions of years. This, however, represents only the time necessary to deposit the rocks which have been formed by denudation from older rocks, and these again from rocks of still greater antiquity. Assuming that the existing stratified rocks have thus passed three times through denudation and deposition, we have a period of 72 million years.

Dr. Haughton, calculating from the observed thickness of rocks down to the Miocene Tertiary, and assuming a period of 8616 years for each foot deposited on the ocean bed, finds for the age of the stratified rocks a period of 1,526,750,000 years! Assuming the rate of denudation, however, at ten times greater in ancient times than at present, and adding one-third for the period since the Miocene Tertiary, he arrives at a final result of 200 millions of years! Dr. Croll doubts the validity of Dr. Haughton's assumptions, especially the total thickness of rock he assumes, viz., 177,200 feet, or over 33 miles.

Mr. A. R. Wallace, adopting Dr. Haughton's thickness, but assuming the sediment to be deposited along a belt of

thirty miles wide round the whole coast line of the globe, finds with an assumed denudation of one foot in 3000 years, a period of 28 million years. This, however, on Dr. Croll's assumption of re-formation and denudation repeated several times, would represent merely a fraction of the time required.

Dr. Croll further shows, from the evidence of remarkable faults in various parts of the world, with downthrows varying from 3000 to 20,000 feet, the enormous amount of solid rock which must have been denuded off the surface of the earth during the progress of geological history. He estimates that three miles of rock have been removed since the beginning of the Old Red Sandstone. This would indicate a period of 45 millions of years. Assuming that the period *before* the Old Red Sandstone was equally long we have 90 millions of years as the "minimum duration of geological time."

These enormous periods of time do not, however, seem to satisfy the demands of biologists and the supporters of the Darwinian theory. Judging "from the fact that almost the whole of the Tertiary period has been required to convert the ancestral Orohippus into the true horse," Professor Huxley believes "that in order to have time for the much greater change of the ancestral ungulata into the two great odd-toed and even-toed divisions (of which change there is no trace even among the earliest Eocene mammals) we should require a larger portion, if not the whole of the Mesozoic or Secondary period," and still longer periods are demanded for the evolution of other animals, "so that on the lowest estimate we must place the origin of the mammalia very far back in Palæozoic

times." Mr. Wallace speaks of possible periods of 200 and even 500 millions of years! To account for the existence of the solar heat during these vast æons of time it would be necessary to increase Dr. Croll's original assumption of a velocity of 476 miles per second very considerably!

Astronomers will not of course deny the mathematical accuracy of Dr. Croll's *conclusions*, but they consider such enormous velocities as improbable, and the collisions themselves equally so. Without the aid of such collisions physicists will not admit that the Sun's life history can be extended backwards beyond a limited number of millions of years. The evidence afforded by geology seems to require a much longer period; biologists and evolutionists demand still more, and hence has arisen a scientific conflict which at present—unless we accept Dr. Croll's theory—there seems no hope of bringing to a satisfactory conclusion.

Further evidence in support of his theory is drawn by Dr. Croll from chemical considerations respecting the constitution of matter and the ether of space. These will be referred to in a subsequent chapter.

CHAPTER IV.

THE FUEL OF THE SUN.

THE dazzling brilliancy of the Sun far exceeds all artificial sources of illumination. It has been shown experimentally that, compared with a standard candle placed at a distance of one metre from the eye, the Sun's light is equal in quantity to 1575 billions of billions of such candles! (1575 followed by 24 cyphers). The *intensity* of the solar light—or the amount of light per square inch of surface—is found to be 90,000 times greater than that of a candle, and 150 times as bright as the lime light! The blackest portion of a Sun spot exceeds the lime light in intensity, and even the electric arc when placed between the Sun's disc and the eye appears as a black spot![1]

The question has often been asked, What is the fuel of the Sun? What is the origin of the vast amount of heat and light which is constantly being radiated by our central luminary into surrounding space? The question is a difficult one to answer if looked at in the light of actual combustion. The amount of fuel necessary to produce the observed effects is so enormous that it seems almost impossible to imagine where the fuel could come from.

[1] Young's *General Astronomy*, pp. 212-14.

Sir William Thomson has calculated that the quantity of fuel required for each square yard of the solar surface would be no less than 13,500 pounds of coal per hour! equivalent to the work of an engine of 63,000 horse-power. This enormous expenditure of fuel would be sufficient to melt a thickness of about 40 feet of ice per minute at the Sun's surface. Sir John Herschel says: "Supposing a cylinder of ice 45 miles in diameter to be continually darted into the Sun *with the velocity of light*, and that the water produced by its fusion were continually carried off, the heat now given off constantly by radiation would then be wholly expended in its liquefaction, on the one hand, so as to leave no radiant surplus; while on the other the actual temperature at its surface would undergo no diminution."[1] He also says[2] the ordinary expenditure of heat by the Sun per minute would suffice to melt a cylinder of ice 184 feet in diameter and in length extending from that luminary to *a* Centauri!

As to the actual temperature of the Sun's surface very various estimates have been made by different computers. Secchi supposed it to be about 10,000,000 degrees of the Centigrade thermometer, and Spörer 37,000 degrees of the same scale, while M. Pouillet thinks that it lies between 1461 and 1761 degrees Centigrade. M. Becquerel, Professor Langley, and Sir William Thomson consider that the temperature of the solar photosphere cannot exceed 3000 degrees Centigrade. According to M. Sainte-Claire-Deville the temperature is somewhere about 2500 to 2800 degrees, and this agrees with subsequent experiments by

[1] *Outlines of Astronomy*, Tenth Edition, p. 258.
[2] *Cape Observations*, p. 446.

Bunsen and Debray. Sir Robert Ball says that "we shall probably be well within the truth if we state the effective temperature of the Sun to be about 18,000° Fahrenheit."[1] Secchi's estimate is probably very excessive and the smaller determinations nearer the truth.

The actual heat of the Sun must, however, be very great. Professor Young says[2]: "When heat is concentrated by a burning glass, the temperature at the focus cannot rise above that of the source of heat, the effect of the lens being simply to move the object at the focus virtually towards the Sun; so that if we neglect the loss of heat by transmission through the glass, the temperature at the focus should be the same as that of a point placed at such a distance from the Sun that the solar disc would seem just as large as the lens itself viewed from its own focus. The most powerful lens yet constructed thus virtually transports an object at its focus to within about two hundred and fifty thousand miles of the Sun's surface, and in this focus the most refractory substances—platinum, fire-clay, the diamond itself—are either instantly melted or dissipated in vapour. There can be no doubt that if the Sun were to come as near us as the Moon, the solid earth would melt like wax."

Messrs. Trowbridge and Hutchins consider that in the solar atmosphere where carbon is volatilised, the temperature is about equal to that of the voltaic arc.

It may be shown that were the Sun's mass composed of coal it would all be consumed in about 6000 years. It has been suggested that the solar heat may be maintained by the fall of meteors on its surface. A pound of coal

[1] *The Story of the Heavens*, p. 495. [2] *The Sun*, p. 267.

falling on the Sun from an indefinite distance would develop by concussion 6000 times the heat that would be produced by its combustion. But the enormous quantity of meteors required for the purpose—about 3800 lb. per square foot per annum—renders this theory very improbable. If the earth were to fall into the Sun, it would maintain its heat for a period of less than a hundred years. Jupiter falling into the Sun would supply its present expenditure for 32,000 years to come; but, in view of the millions of years indicated by geological records, even this period must be considered as comparatively short. Another objection to this theory is that the quantity of matter required would, in the course of ages, add appreciably to the Sun's mass, and this increase of mass would derange the motions of the planetary system. The meteoric theory of the Sun's heat must therefore be abandoned.

The theory now generally accepted by astronomers is that advanced by the eminent German physicist Helmholtz, which ascribes the heat of the Sun to the shrinkage of its mass caused by gravitation. It may be shown mathematically that this shrinkage would undoubtedly produce the observed effect; and as gravitation must inevitably act on the component particles of the Sun's mass, it seems quite unnecessary to look further for a satisfactory theory. The amount of shrinkage required to account for the present solar radiation is so small that the diminution in the Sun's apparent diameter could not be detected by the most refined instruments of measurement. Sir William Thomson has shown that this shrinkage would amount to only thirty-five metres on the radius per annum, or one ten-thousandth of its length in 2000 years, a quantity

quite inappreciable. It would take over 10,000 years to reduce the Sun's diameter by one second of arc.

According to Helmholtz's theory the Sun's heat was originally generated by the collision of two masses, as in Dr. Croll's theory, but differing from that theory in the supposition that the bodies approached each other under the effects of gravitation *alone* and not with any initial velocity. In some books it is "paradoxically stated" that the Sun is actually becoming hotter owing to condensation, but this is quite incorrect. As Sir William Thomson points out, "cooling and condensation go on together." In fact, as the Sun has been gradually losing heat for ages past, the amount of heat lost by radiation must be in excess of that gained by shrinkage, and as this process is probably still in progress the Sun must be actually cooling down. Of course this cooling process is excessively slow, so slow, indeed, that one estimate makes the maximum loss not more than 1° Centigrade in seven years.

According to Sir William Thomson, if the Sun's heat could be maintained by shrinkage until 20 million times the present annual expenditure is radiated away, the Sun's diameter would be reduced to one-half what it is at present, and its density would be increased to about 11·2, or about the specific gravity of lead. This would probably put a stop to all further shrinkage "through overcrowding of the molecules."

Supposing the Sun to have been radiating out heat for the past 15 million years, the solar radius "must have been four times as great as at present." Sir William Thomson is not disposed to admit much more than 12 million years as the past duration of the Sun's history;

but, as has been shown in the preceding chapter, this period, immense as it is, will not satisfy the demands of geologists. To meet this difficulty Dr. Croll has advanced his "Impact Theory," which has been already considered. (Chapter III.)

A necessary detail of Helmholtz's theory is that the Sun must be in a fluid state from its surface to its centre. Were this not so it would soon grow dark, "as the conducting power of no known solid would suffice to maintain the incandescence." The idea of a solid nucleus enclosed in a fiery envelope must therefore be abandoned and consigned to the limbo of all such uncritical theories.

Sir William Thomson thus describes the action which would probably take place during the formation of the Sun according to the gravitation theory[1]: "Think of two solid globes each of the same mean density as the earth and of half the Sun's diameter, given at rest, or nearly at rest, at a distance asunder equal to twice the earth's distance from the Sun. They will fall together and collide in exactly half a year. The collision will last for about half an hour, in the course of which they will be transformed into a violently agitated incandescent fluid mass flying outwards from the line of motion before the collision, and swelling to a bulk several times greater than the sum of the original bulks of the two globes. How far the fluid mass will fly out all round from the line of collision it is impossible to say. The motion is too complicated to be fully investigated by any known mathematical method. A mathematician with sufficient patience might, however, approximate to the truth. After a series of oscillations it will subside,

[1] *Good Words*, April 1887.

probably in the course of 2 or 3 years, into the globular star of about the same dimensions, heat, and brightness as our present Sun, but differing from him in this, that it would have no rotation.

"If, however, each had a transverse motion—in opposite directions—of 1·89 metre per second, the result would be a globe, like our Sun, rotating in 25 days. If the transverse velocity be anything more than 0·71 of a kilometre, they would escape collision, and would revolve in equal ellipses round the centre of inertia in a period of one year, just grazing one another's surfaces every time they came round to the nearest points of their orbits. If the initial transverse velocity be less than, but not much less than 0·71 of a kilometre per second, there will be a violent grazing collision and two bright suns, solid globes bathed in flaming fluid will come into existence in the course of a few hours, and will commence revolving round their common centre of inertia in long elliptic orbits in a period of little less than a year. Tidal interaction between them would diminish the eccentricity of their orbits, and, if continued long enough, would cause them to revolve in circular orbits round their centre of inertia with a distance between their surfaces equal to 6·44 diameters of each."

The bearing of the latter portion of Sir William Thomson's remarks on the possible origin of binary stars will be obvious to the reader. The "violent grazing collisions" in a period of about a year seem also to suggest a possible explanation of the nature of some of the variable stars of which the periods of several do not differ much from 365 days. Indeed, this is the theory of variable stars advanced by Professor Lockyer in his "Meteoritic

Hypothesis," but in this theory the revolving masses are supposed to be swarms of meteorites and not solid bodies. The bright lines observed in some of the long-period variables when near a maximum of light indicate a great increase of heat, which may probably be due either to collisions of thousands of meteorites clashing together, or to solid bodies rendered incandescent by a "violent grazing collision."

The discoveries which have been made respecting the chemical constitution of the Sun will be discussed in a subsequent chapter.[1]

[1] See Chapter VII., "Celestial Chemistry."

CHAPTER V.

THE LUMINIFEROUS ETHER.

THE corpuscular, or emission, theory of light originally supported by eminent scientific men, even by Sir Isaac Newton himself, having been found incapable of explaining many optical phenomena, was abandoned, and the present generally accepted wave theory was substituted for it. This theory explains satisfactorily so many phenomena that, although possibly not a perfect theory, it has held its ground against numerous attacks which have been made on it from time to time. The theory that light is propagated in waves evidently necessitates the hypothesis of a medium to transmit these waves through space.

Some have suggested that this medium may perhaps consist of some kind of gaseous matter in a highly rarefied form; but the great objection to this hypothesis is, that, however attenuated we may suppose such a gaseous medium to be, it would inevitably exercise a retarding influence on the motions of the planets round the Sun, which in the course of time could not fail to be detected by astronomical observations. We must therefore conclude that the luminiferous ether, as this hypothetical medium is called, cannot possibly consist of any form of matter with which we are familiar.

It may be asked, what, then, is the constitution of the ether? This is a difficult question, and one which has not yet been satisfactorily answered. Sir John Herschel says: "Every phenomenon of light points strongly to the conception of a solid rather than a fluid constitution of the luminiferous ether, in the sense *that none of its elementary molecules are to be supposed capable of interchanging places*, or of bodily transfer to any measurable distance from their special and assigned localities in the universe." That the ether is not of the nature of solids, such as we know, is evident. It can therefore only be considered as a solid in the sense of the words which Sir John Herschel writes in italics in the above passage. As no terrestrial substance could possibly possess the property referred to without being an actual solid, it is clear that the ether cannot consist of matter in any form.

In our ignorance of its real constitution we can only consider it as a perfect, or nearly perfect, fluid, possessing *some* of the properties of a solid. This may seem a rather paradoxical conception, but as all our experience of material substance is derived from matter in its various forms, we have no right to deny that a medium distinct from matter, and apparently possessing paradoxical properties, may exist in interstellar space.

M. Hirn says that, "to explain a secular acceleration of 0·5″ in the mean motion of the Moon, it would be sufficient if 1 kilogramme of gas were distributed over 975,000 cubic kilometres of space, a rarefaction one million times greater than that of a Crooke's vacuum of the millionth of an atmosphere. But the effect of the shock of the particles of this rarefied gas against a body like the Moon as it moved

forward in its orbit would be to raise the gas to a temperature of 38,000° C., and inconceivably attenuated as this interplanetary atmosphere would be the Moon would yet come into contact with 600 kilogrammes of it in each minute of time."[1] The effect of the earth's motion through such a gas would be that its atmosphere would be rapidly stripped off layer by layer.

We may compare the elastic force of the ether, or its resistance to compression, with that of air by the following method, due to Sir John Herschel. The velocity of light is known to be about 186,400 miles per second. That of sound is about 1090 feet per second, but were there no heat given out by the compressing force of the sound-waves the velocity would be only 916 feet a second. As we cannot suppose any heat to be developed by compression in a perfect fluid like the ether, we must compare the *smaller* velocity of sound with the velocity of light. This makes the velocity of light about 1,074,525 times that of sound. Now from the theory of sound it follows that in media of different elasticities, but otherwise similarly constituted, these elasticities are to each other as the squares of the velocities of the waves which are propagated through them. It follows therefore that the elasticity of the ether exceeds that of air in the ratio of the square of 1,074,525 to 1, or about 1,154,600,000,000 times.

This calculation is, however, based on the assumption that the ether and the air are similarly constituted. As, however, air is undoubtedly a form of matter and the ether is probably not, the two fluids cannot perhaps be properly compared. The above calculation will, however, show that

[1] *Nature*, April 25th, 1889.

whatever the constitution of the ether may be its elastic force must be enormous. The fact that light has a finite and not an infinite velocity seems to imply that the ether is not an *absolutely perfect* fluid, and that it possesses some property which restricts the propagation of light to a limited, although enormous, velocity.

Recent researches seem to show that electricity may be, like light and heat, merely "a mode of motion." If this be true, the question suggests itself, would the luminiferous ether also serve for the transmission of electricity, or is it necessary to imagine the existence of a separate electrical medium? Now to fill the whole of interstellar space with different media, one for the propagation of light, another for the transmission of electricity, and perhaps a third for the conveyance of gravitative action, would be an hypothesis as improbable as it is certainly unphilosophical. Physicists have therefore sought for some evidence to show that the luminiferous ether may possibly act as a vehicle for electrical phenomena. Such evidence is fortunately forthcoming, and the results are very suggestive.

Faraday found that when glass was subjected to the action of a powerful magnetic field it caused a rotation of the plane of polarisation of light, and a similar result was established for gases by the experiments of Kundt, Lippich, and Röntgen. An intimate relation between light and magnetism has been demonstrated by Dr. Kerr of Glasgow. Polishing the poles of an electro magnet, and examining with an analyser a beam of plane polarised light reflected from the polished surface, he found that when the pole is the positive one the plane of polarisation of the reflected beam is turned in the opposite direction to that of a beam

reflected from the negative pole. Professor Fitzgerald has shown theoretically that Dr. Kerr's results are a necessary consequence of the reflection of light from a magnetic surface, so that observation and theory are here in perfect harmony. Dr. Kerr also finds that the property of elliptic polarisation is produced by a beam of light passed through a transparent insulator, like glass, when the insulator is under a powerful electrical strain.

Some recent remarkable experiments made by Dr. Hertz have shown that an electric current may be reflected and refracted like a beam of light, and that the electro-magnetic and luminiferous disturbances are probably propagated in the same medium and with the same velocity although with waves of different length.

If the medium through which light is propagated be identical with that which conveys electrical action, we might expect that the velocity of transmission of each would be the same. This we find to be actually the case. Experiments show that the velocities in air are practically identical—each about 300 millions of metres, or 186,414 miles a second. For other media, through which light and electricity can both pass, we have for light the velocity inversely proportional to the refractive index of the medium (that of air being unity), and for electrical action the velocity proportional to the square root of the specific inductive capacity (also with reference to that of air). If therefore the velocities are the same, we should find the former quality equal to the latter (for waves of light of infinite period).

Experiments do not, however, yield so close an agreement in this case, some media showing an identity of

the two values, while for others there is a discrepancy in the results, which, according to Clerk Maxwell, "is greater than can be accounted for by errors of observation, and shows that our theories of the structure of bodies must be much improved before we can deduce the optical from the electrical properties." The observed difference may, however, possibly be due to some modification in the density of the ether in the media experimented upon.

Perhaps some time in the coming century science, with its advancing strides, may give to mankind some slight insight into the constitution of this incomprehensible fluid; but at present we can only say with the Psalmist, "Such knowledge is too wonderful and excellent for me: I cannot attain unto it"; and to most of us this knowledge will never come till we find ourselves afloat at last on the "shoreless ocean of eternity."

CHAPTER VI.

THE CONSTITUTION OF MATTER.

Τὸν ἐμὸν πέπλον οὐδείς πω θνητὸσ ἀπεκάλυψε.[1]

"Shall any gazer see with mortal eyes
Or any searcher know by mortal mind?
Veil after veil will lift—but there must be
Veil upon veil behind."[2]

SIR EDWIN ARNOLD.

THE question whether matter is continuous or homogeneous in structure and infinitely divisible, or whether it is composed of ultimate atoms of excessively small but definite dimensions, is one which has exercised the minds of scientific men in all ages. The former theory was advanced by the ancient philosopher Anaxagoras, and was adopted in more recent times by Descartes, and it forms the foundation of Spinoza's philosophy. The latter hypothesis was proposed by Democritus and developed by Lucretius in ancient times, and it has been almost universally adopted by modern physicists. The fact that all known bodies are more or less compressible has led to the conclusion that matter is really composed of ultimate indivisible atoms which, grouped together by "chemical

[1] "My veil no mortal ever withdrew." An inscription in the temple of Athene Isis, at Sais on the Nile.

[2] *The Light of Asia*, Book the Eighth.

affinity," form molecules, and that aggregations of myriads of these molecules constitute matter as we know it. Other properties of matter are also in favour of the atomic theory. Professor Clerk Maxwell says: "The theory that bodies apparently homogeneous and continuous are so in reality is in its extreme form a theory incapable of development. To explain the properties of any substance by this theory is impossible";[1] and it has been shown by Cauchy that, if matter were homogeneous and not molecular, there would be no dispersion of light through a glass prism.

According to the molecular theory of matter, solid bodies are composed of an immense number of molecules all vibrating round a mean position. On the application of heat, which, as Professor Tyndall has shown, is merely "a mode of motion," the energy of the vibrating molecules is increased, and the solid gradually passes into the liquid state. A further rise of temperature increases the molecular motion to such an extent that the molecules separate from the others, and each follows its own path. The liquid then passes into the gaseous state, and the pressure of a gas against the surface of a vessel containing it—which is known to increase with the temperature if the volume is kept constant—is explained by the impact of the moving molecules on the bounding surfaces.

From a consideration of the motion of light in solids and liquids Cauchy found that the constituent atoms of matter are so small that 400 millions go to an inch. From electrical experiments Sir William Thomson calculated that the "ultimate particle" is about the 700 millionth of an inch in diameter. From observations of gaseous pheno-

[1] *Encyclopædia Britannica*, Ninth Edition, 1875, Article "Atom."

mena Clausius and Clerk Maxwell concluded that the size of the particle is the 500 millionth part of an inch. These different estimates are not very widely discordant, considering the extremely difficult character of the investigation. Taking a mean of the three results we may conclude that it would take 500 million atoms of ordinary matter placed in a line to measure an inch! Sir William Thomson says: "Imagine a globe of water or glass as large as a football to be magnified up to the size of the earth, each constituent molecule being magnified in the same proportion. The magnified structure would be more coarse-grained than a heap of small shot, but probably less coarse-grained than a heap of footballs."[1]

That the ultimate atoms of glass must be excessively small may be imagined from the fact "familiar to opticians, that fine rulings on glass whose distance apart is less than half of the wave length of light are readily resolvable with optical distinctness by our modern microscopes, while the intimate texture of the glass is apparently as far removed from resolution as with the unarmed eye." Professor Tyndall says: "Thus does the eye of science pierce to what Newton called 'the most secret and noble works of Nature,' and make us at home amid the mysteries of a world lying in all probability vastly farther beyond the range of the microscope than the range of the microscope, at its maximum, lies beyond that of the unaided eye."

The relative distance between two molecules of our atmosphere is probably about 50 times the diameter of a

[1] *Proceedings of the Royal Institution of Great Britain*, Vol. X., Part II., p. 213.

molecule. Lawn-tennis balls placed on a smooth surface at the angles of a series of equilateral triangles (touching each other), the sides of which are in length fifty times the diameter of a ball (about 10 feet), will represent these gaseous molecules; and the length of the mean excursion of the vibrating molecules, a "free path" as it is called, would be about 3000 times the diameter of a ball, or 60 times the side of the equilateral triangle in the above illustration.

With reference to the actual constitution of the ultimate particles of matter, Sir Isaac Newton supposed the atoms to be of a spherical shape and infinite hardness. Supporters of this hypothesis are still to be found, but Sir William Thomson says, "We are forbidden by the modern theory of the conservation of energy to assume anything short of perfect elasticity of the ultimate molecules of matter." That the atom is merely a centre of force, a mathematical point capable of displaying the forces of attraction and repulsion, was advocated by Boscovitch and Faraday; but this seems a too purely metaphysical conception to satisfy the requirements of the physicist and mathematician.

Probably the most philosophical theory hitherto proposed is that advanced by the eminent German physicist Helmholtz, who supposes the atom to be an excessively minute vortex-ring, originally formed by some rotational movement in the ether of space. Such rings would be indestructible, and they would possess the properties of perfectly elastic bodies. The hypothesis that the luminiferous ether is a perfect fluid—that is, homogeneous and not molecular in structure—differentiates it at once from

ordinary matter which is supposed to consist of atoms of excessively small but definite dimensions.

If we consider with Helmholtz that these atoms are vortex-rings produced by some Creative act in the ether, it will be seen at once that the two hypotheses are consistent with each other. According to Helmholtz's theory, when a vortex-ring is formed in a perfect fluid like the ether, it ceases to be ether, and becomes a particle of matter, which is indestructible as far as our experience goes. It can never be destroyed except by the same Creative power which first called it into being. Matter may, by the application of heat or cold or chemical action, be changed into apparently various forms—solid, liquid, or gaseous; but it can never, by any process with which we are acquainted, be annihilated, or resolved back into the ether from which it was originally evolved.

Dr. Croll objects to the "vortex-ring" theory of matter that it violates the First Law of Motion. He argues that the so-called centrifugal force of the rotating atom necessitates the hypothesis of resistance from without to counterbalance it, but that the idea of resistance is inadmissible in a perfect fluid like the ether of space. He says: "If this fluid can offer no resistance to the passage of the atom as a whole, how then does it manage to offer such enormous resistance to the materials composing the atom, so as to continually deflect them from the straight path and compel them to move in a curve? The centrifugal force of these vortex-atoms must be enormous, for on it is assumed to depend the hardness or resistance of matter to pressure. Now the centripetal force which balances this centrifugal force must be equally enormous. If, then, this perfect

fluid outside the vortex-atom can exert this enormous force on the revolving material without being itself possessed of vortex-motion, there does not seem to be any necessity for vortex-motion in order to produce resistance. In short, how is the existence of the atom possible under the physical conditions assumed in the theory?"[1]

Here, however, there seems to be some misconception of the theory. Dr. Croll speaks of "the materials composing the atom," but, according to the vortex-ring theory, the ultimate atom is not composed of "materials" at all—if by "materials" matter is intended—but simply of rotating portions of the ether (which is not matter), aggregations of numbers of such atoms constituting what we know as matter. As to the ether offering no resistance to the passage of an atom through it, it must be remembered that resistance to motion in a fluid does not depend upon pressure, but upon friction, which by hypothesis does not exist in a perfect fluid. As, moreover, the vortex-atom has stood—at least in the preliminary stages through which it has hitherto passed—the test of the powerful mathematical analysis applied to it by such giant intellects as Helmholtz and Thomson, it seems clear that Dr. Croll's objection, founded on the supposed "centrifugal force" in the vortex-atom, is more apparent than real.

Professor Lodge says: "These whirling portions constitute what we call matter; their motion gives them rigidity, and of them our bodies, and all other material bodies with which we are acquainted, are built up. One continuous substance filling all space, which can vibrate as light; which can be sheared into positive and negative

[1] *Stellar Evolution*, pp. 89, 90.

electricity, which in whirls constitutes matter, and which transmits by continuity, and not by impact, every action and reaction of which matter is capable,—this is the modern view of ether and its functions."[1]

The Nebular Hypothesis assumes that the Solar System was evolved by condensation from a nebulous mass which originally extended beyond the orbit of Neptune. Its condition at that remote epoch of cosmical history is supposed to be represented by the gaseous nebulæ, visible in the telescope. If this be so, if these masses of luminous gas represent solar systems in their initial stage, we are brought face to face with a great difficulty. The spectroscope shows that these gaseous masses consist of simply hydrogen and another substance, which was for some time supposed to be nitrogen, but is now found *not* to be identical with that element. Indeed, in some cases the presence of a solitary bright line in the spectrum suggests that they are composed of a single element.

Now the known elements of which terrestrial substances are composed exceed sixty in number, and of these more than a dozen have been identified by the spectroscope in the Sun. How then could all these have been produced out of a nebulous mass containing only one, two, or three elements? No satisfactory reply to this question has ever been given. But the enigma would be solved could we assume that the known elements are really compound bodies and were originally evolved from one or more simple substances.

Professor F. W. Clarke says: "It is plain that the nebular hypothesis would be doubled in importance, and

[1] *Nature*, February 1st, 1883, p. 330.

our views of the universe greatly expanded, if it could be shown that an evolution of complex from simple forms of matter accompanied the development of planets from the nebulæ. Evolution could look for no grander triumph." Chemistry has not, however, succeeded in decomposing any of the known elements into simpler substances. Professor Lockyer's spectroscopic researches seem to show evidence in favour of the idea that some of the elements are actually dissociated in the intense heat of the solar photosphere, but his results have not been generally accepted by chemists and astronomers.

At the meeting of the Vienna Academy of Sciences in December 1887 a paper was read by Professor Gruenwald, of Prague, in which he asserts his discovery of the compound nature of magnesium and carbon. I am not aware whether this supposed discovery has been confirmed or disproved. In the *Astronomische Nachrichten*, No. 2797, he also attempts to show that hydrogen is really a compound body composed of two elements, namely, "Coronium," which gives the 1474 K line of the solar corona, and "Helium," the unknown substance giving the line D_3. This line D_3 is visible in the spectrum of the great nebula in Orion and some other nebulæ. It has also been seen in the spectrum of the star P Cygni ("Nova" 1600), and in that of U Orionis, the so-called "Nova" of 1885.

The hypothesis of the non-elementary character of the chemical elements seems to be looked upon with favour by some of our leading chemists and physicists, and possibly it may some day be discovered that they have all been evolved from one original simple substance, to which Mr. Crooks has given the provisional name of "Protyle."

CHAPTER VII.

CELESTIAL CHEMISTRY.

SOON after the invention of the spectroscope and its application to the chemistry of terrestrial substances, an attempt was made to extend the investigation to the chemistry of the Sun and other celestial bodies. This attempt has met with complete success, and some account of the general results which have been arrived at in this field of scientific inquiry may prove of interest to the reader.

When the Sun's light is examined with a spectroscope the resulting rainbow-tinted band of light is seen to be crossed transversely by a number of fine dark lines. These lines were first carefully observed by Fraunhofer in the year 1814, and are still known by the name of "Fraunhofer's lines." Fraunhofer found that the dark line D in the yellow portion of the solar spectrum coincided exactly in position with the *bright* line D of the spectrum of sodium; but it was not till 1859 that it was clearly demonstrated by Kirchhoff that the dark line D in the Sun's spectrum was due to the light ~~(of burning sodium)~~ shining through ~~its own~~ vapour. This remarkable and interesting discovery—the reversal of the bright spectrum lines of a chemical element due to absorption of light by the vapour of the same substance—laid the foundation of celestial chemistry, and

solved the problem of the chemical constitution of the heavenly bodies.

The discovery thus made of sodium in the Sun was quickly followed by the detection of other chemical elements in the solar spectrum. In the case of iron no less than 460 dark lines in the Sun's spectrum, corresponding *exactly* with 460 bright lines in the spectrum of incandescent iron, have been observed and mapped by Kirchhoff and Ångström; and Thalén has found 170 lines in the spectrum of the metal titanium coinciding with dark lines in the solar spectrum. The conclusion is therefore irresistible that the metals iron and titanium exist in the Sun's atmosphere. Kirchhoff says: "This coincidence must be produced by some cause; and a cause can be assigned which affords a perfect explanation of the phenomenon. The observed phenomenon may be explained by the supposition that the rays of light which form the solar spectrum have passed through the vapour of iron, and have suffered the absorption which the vapour of iron must exert."

According to Professor Lockyer the following elements exist in the glowing envelope of our central luminary[1]:—

Hydrogen.	*Zinc.*	Palladium.
Sodium.	*Cobalt.*	Molybdenum.
Calcium.	*Aluminium.*	Indium.
Magnesium.	Copper.	Lithium.
Iron.	Strontium.	Rubidium.
Manganese.	Lead.	Cæsium.
Titanium.	Cadmium.	Bismuth.
Chromium.	Cerium.	Tin.
Nickel.	Uranium.	Glucinum.
Barium.	Potassium.	Lanthanum.
	Vanadium.	Yttrium or Erbium.

[1] *The Chemistry of the Sun*, pp. 158 and 220.

Those printed in italics *certainly* exist in the Sun; the others with more or less probability.

To the above list Professor Rowland adds, from his own observations, silicon, carbon, scandium, zirconium, niobium, palladium, neodymium, germanium, rhodium, and silver; but omits from his list uranium, indium, lithium, rubidium, cæsium, and bismuth. He finds 2000 lines or more of iron in the solar spectrum, and 200 or more of carbon.

The next step forward in celestial chemistry was made in the year 1862 and 1863 by Drs. Huggins and Miller, who attempted to determine the character of the spectra of some of the brighter stars.[1] This was a matter of no small difficulty, as the light of even the brightest star is so small that the necessary dispersion by the prism renders the dark lines of the stellar spectrum not only difficult to measure but even to see. The finest nights and a telescope of considerable light-grasping power are necessary in these delicate observations. Huggins and Miller were, however, successful in their efforts, and succeeded in observing the spectra of Sirius, Vega, Arcturus, Capella, Betelgeuse, Pollux, Castor, and some other stars. In the brighter stars they found the dark lines "as fine and as numerous as they are in the solar spectrum." *All* the spectra observed did not, however, agree with the Sun's spectrum, some of them differing in the detail of the dark lines visible. They found a marked difference in the spectra of the two stars Aldebaran (*α* Tauri) and Betelgeuse (*α* Orionis), the former of these stars giving a spectrum with

[1] A few of the solar lines had been previously recognised by Fraunhofer and Donati in some of the brighter stars, but nothing very definite was published on the subject.

fine lines, very similar to that of the Sun, while the latter showed a spectrum with dark bands.[1] In the case of Sirius the lines of hydrogen appeared very broad and dark, indicating a different chemical constitution, or rather a different condition of the stellar photosphere.

These results have been abundantly verified by subsequent observations, and the stars have been divided into types according to the character of their spectra. Secchi proposed four types of stellar spectra. The following is Vogel's classification, according to Lockyer[2]:—

Class I.—*Spectra in which the Metallic Lines are extremely Faint or entirely Invisible.* The most refrangible parts, blue and violet, are very vivid. The stars are white.

(*a*) Spectra in which the lines of hydrogen are very strong.

(*b*) Spectra in which the lines of hydrogen are wanting.

(*c*) Spectra in which the lines of hydrogen and D_3 are bright.

Class II.—*Spectra in which the Metallic Lines are Numerous and very Visible.* The blue and violet are relatively weaker; in the red part there are sometimes faint bands. The colour of the star is clear bluish-white to deep reddish-yellow.

(*a*) Spectra with numerous metallic lines, especially in the yellow and green. The lines of hydrogen are generally strong, but never as strong as in the stars of Class I. In some stars they are invisible, and then faint bands are generally seen in the red formed by very close lines.

[1] This difference in the spectra is the more remarkable as the two stars are very similar both in brightness and colour—at least to my eye.

[2] *The Meteoritic Hypothesis*, p. 345.

(*b*) Spectra in which, besides dark lines and isolated bands, there are several bright lines.

CLASS III.—*Spectra in which, besides the Metallic Lines, there are numerous Dark Bands in all parts of the Spectrum, and the Blue and Violet are remarkably Faint.* The stars are orange or red.

(*a*) The dark bands are fainter towards the red.

(*b*) The bands are very wide, and the principal are fainter towards the violet.

This subdivision of Secchi's Class III. is objected to by Lockyer and Pechüle, but this will be referred to further on. We will now consider each class separately.

CLASS I.—The following bright stars show spectra of this type: Sirius, Vega, Regulus (*a* Leonis), Spica (*a* Virginis), Fomalhaut (*a* Piscis Australis), Castor, *a* Ophiuchi, *a* Coronæ Borealis, β, γ, δ, ϵ, ζ, and η Ursæ Majoris, Algol (β Persei), and others.

(*a*) This subdivision includes Sirius and Vega. The hydrogen lines in Sirius are remarkably strong and broad, and may be seen even with small optical means. I have seen them distinctly with a McClean's star spectroscope attached to a three-inch refractor. According to Lockyer's Meteoritic Hypothesis, stars in this sub-class are the hottest bodies in the universe.[1] It is worthy of notice that all the stars which have been found by the spectroscope to be close doubles, as Spica, ζ Ursæ Majoris, and β Aurigæ, belong to this class, and also the Algol variables, of which the spectra have been examined, viz., Algol, λ Tauri, and U Monocerotis.

(*b*) This subdivision includes the brighter stars in Orion, with the exception of *a* (Betelgeuse).

[1] *The Meteoritic Hypothesis*, p. 374.

(*c*) Includes β Lyræ, γ Cassiopeiæ, P (34) Lyræ, and some small stars. According to Lockyer's Meteoritic Hypothesis stars in this sub-class are increasing in temperature.[1] With reference to 34 Cygni, Lockyer says: "In addition to the hydrogen lines there is a bright line in P Cygni, the wave-length of which I have found to be about 447. This appears to be coincident with Lorenzoni's *f* of the chromosphere spectrum, and it is also seen in the spectrum of the nebula in Orion. In all three cases it is associated with the line D_3."[2]

Class II.—The following bright stars show spectra of this type: Capella (α Aurigæ), Arcturus (α Boötis), Aldebaran (α Tauri), Pollux (β Geminorum), α Cygni, α Hydræ, γ Leonis, α Serpentis, α Ursæ Majoris, etc.

(*a*) This subdivision includes stars with spectra similar to that of our Sun. The spectrum of Capella very closely resembles the solar spectrum; but in others, as in Aldebaran and α Cygni, there are marked variations.

(*b*) The variable star R Geminorum is an example of this sub-class. According to Lockyer stars in this sub-class are increasing in temperature.[3]

Class III.—This class, which includes the banded or "columnar" spectra,[4] is divided into two sub-classes by Vogel, as above described. Secchi, however, restricted Class III. to stars of Vogel's sub-class (*a*), and placed the stars of sub-class (*b*) in another class, Class IV. Pechüle and Lockyer defend Secchi's classification on the

[1] *The Meteoritic Hypothesis*, p. 375. [2] *Ibid.*, p. 409. [3] *Ibid.*, p. 375.

[4] In addition to the "bands" characteristic of this type of spectra photographs reveal the presence of an underlying system of "lines" similar in general character to those of the solar spectrum.

ground that the spectra (*a*) and (*b*) are very dissimilar. Stellar spectra are known which are intermediate in character between Classes I. and II., and between II. and III., but no well-marked transition spectrum between Secchi's Classes III. and IV. has yet been observed. According to Pechüle, "le IV. type représenterait une phase bien distincte, la dernière peut-être avant l'extinction totale." Vogel's sub-class (*a*) includes α Herculis, Betelgeuse (α Orionis), α Ceti, β Pegasi, μ Cephei, χ Cygni, U ("Nova") Orionis, and numerous other stars, many of which are variable in light. In the spectra of Betelgeuse and β Pegasi the hydrogen lines are only obscurely visible.

Vogel's sub-class (*b*)—equivalent to Secchi's Class IV.—includes 19 Piscium, U Hydræ, and others, some of which are also variable. This type is a comparatively rare one. It includes at present only 113 stars, according to Espin, down to magnitude 8·8.

In the spectra of these stars the characteristic dark bands agree exactly in position with the *bright* bands of the hydrocarbon spectrum, such as are shown by burning alcohol. They have been called "carbon stars," and show no evidence of free hydrogen. Underlying the banded spectrum in both Classes III. and IV., another spectrum, with fine lines somewhat similar to the solar spectrum, has been observed.

Lockyer thinks that "stars of Vogel's Class III. *a* are of a cometary character and a little more condensed than the bright-line stars."[1] According to his *Meteoritic*

[1] *The Meteoritic Hypothesis*, p. 361. Lockyer considers that these stars "cannot be masses of vapour like our Sun, but they are unquestionably clouds of incandescent stones," p. 350.

Hypothesis, "stars of Class III. *a* are still increasing in temperature by the condensation due to gravity, while the red stars of Class III. *b* are at a nearly equal mean temperature, but are cooling bodies." [1]

Still greater difficulty is experienced in the observation of the spectra of those faint objects, the nebulæ. The extreme faintness of some of these is thus described by Dr. Huggins, who was the first to examine them with the spectroscope: "The light of some of those visible in a moderately large instrument has been estimated to vary from $\frac{1}{1500}$ to $\frac{1}{20000}$ of the light of a single sperm candle consuming 158 grains of material per hour, viewed at a distance of a quarter of a mile; that is, such a candle a quarter of a mile off is 20,000 times more brilliant than the nebulæ." Of 70 nebulæ examined by Dr. Huggins about one-third showed a spectrum of one, two, three, or four lines, indicating a gaseous constitution. "The light of the nebulæ and clusters become spread out by the prism into a spectrum which is apparently continuous." One of the bright lines visible in the nebular spectra has been shown to be certainly due to hydrogen.[2]

In his first observations Dr. Huggins was disposed to attribute another of the nebular lines to nitrogen, but recent careful measures have shown him that the line does not really coincide with a line of nitrogen, but is distinct from it. Lockyer considers that one of the bright lines in the spectrum of the great nebula in Orion coincides with

[1] *The Meteoritic Hypothesis*, p. 376.

[2] It has been shown experimentally that when the light of glowing hydrogen is reduced to a certain point, only one line, the blue line F, remains visible. The G line and other lines of hydrogen have, however, also been photographed in the spectrum of the Orion nebula by Dr. Huggins.

the edge of a magnesium fluting. Dr. Huggins, however, finds that such is not the case, but that the nebular line falls "within the termination of the magnesia band,"[1] or towards the blue end of the spectrum. Dr. Huggins has arrived at the same result with the planetary nebula Σ 5 (G. C. 4234), and his observations on this nebula have been confirmed by Mr. Keeler at the Lick Observatory.

The great nebula in Andromeda, although somewhat similar in appearance to the nebula in Orion, shows a totally different spectrum. Instead of bright lines we have here a continuous spectrum, but with the red end deficient. Although this nebula has never been resolved into stars, the evidence of the spectroscope shows that it is not gaseous. Observations recently made by Dr. and Mrs. Huggins have shown that the red end of the spectrum, although very faint, is distinctly visible when carefully looked for. Mrs. Huggins says that if an oil lamp is placed "at such a distance and in such a manner that its spectrum is photometrically equivalent to the nebula spectrum, observed simultaneously with it, it will be seen that the lamp spectrum is cut off, as is the nebular spectrum."[2] Lockyer thinks that this great nebula consists of swarms of meteors, and that it is in a more condensed state than the nebula in Orion.

The difference in the colours of stars may, in some cases at least, be due to a difference in their chemical constitution. For instance, in the beautiful double star Albireo (β Cygni) it has been found that in the spectrum of the orange-coloured component there are very few dark lines

[1] *Proceedings of the Royal Society*, Vol. XLVIII., p. 203.
[2] *The Observatory*, December 1890.

in the orange portion of the spectrum, most of the lines being confined to the blue and red. In the blue star, on the contrary, there are a great number of dark lines in the red and yellow and comparatively few in the blue: hence the blue light predominates. In this case, then, the difference of colour is due to a real difference in physical constitution, and not merely to an effect of contrast.

Further particulars respecting stellar spectra will be found in the chapter on the Meteoritic Hypothesis (Chapter VIII.).

CHAPTER VIII.

THE METEORITIC HYPOTHESIS.

AN elaborate and interesting volume, containing a statement of the grounds on which he has based his meteoritic theory of the universe, was published by Professor Lockyer towards the close of the year 1890.[1] In this work the able and ingenious author has worked out his hypothesis in great detail; and a review of the principal facts and arguments advanced by Lockyer and also by his opponents may prove of interest both to those who accept and those who reject his views.

Professor Lockyer commences his work with an account of the falls of meteoric stones recorded in history. The earliest of these dates back so far as 1478 B.C., but of course with some uncertainty. Falls are noted by Plutarch in 705 B.C., and by Livy in 654 B.C. Other falls are recorded at the river Ægospotamus, 468 B.C., and at Pessinuntia in Phrygia, 264 B.C. In the Chinese annals of Ma-tuan-lin, Biot has found a record of sixteen falls between the years 644 B.C. and A.D. 333.

In the year A.D. 1492, November 16th, a stone weighing

[1] *The Meteoritic Hypothesis. A Statement of the Results of a Spectroscopic Inquiry into the Origin of Cosmical Systems* (Macmillan & Co., 1890).

260 lb. fell near the town of Ensischeim in Alsace. This stone is still preserved in the Town Hall.

In 1622 a stone fell in Devonshire, and in 1628 another in Berkshire. On December 13th, 1795, a stone weighing 56 lb. fell about ten yards from a labourer working near Wold Cottage, Thwing, Yorkshire. The fall was accompanied by a loud explosion.

On April 26th, 1803, a large number of stones fell near l'Aigle, in the department of Orne, France.

On September 10th, 1813, several stones were seen to fall between the lands of Scagh and the village of Adare (in the neighbourhood of Patrick's Well), in the county of Limerick, Ireland. One of them weighed 17 lb. Another weighing about 74 lb. fell at the same time in the lands of Brasky, about three miles distant from the others.

On April 20th, 1876, a piece of iron weighing 7¾ lb. fell at Rowton, near Wellington, Shropshire. It detonated like the discharge of heavy artillery, and penetrated the ground to a depth of eighteen inches.

On March 14th, 1881, a stone "weighing 3 lb. 8¼ oz. was seen to fall by four persons near Middleborough, Yorkshire. It was accompanied by a whizzing or rushing noise in the air, and made a hole in the ground 11 inches deep. The stone was warm when felt at the bottom of the hole a few minutes after its descent."[1]

On May 10th, 1879, a meteor exploded at Esterville, Emmet county, Iowa (U.S.A.), and fragments weighing 170 and 500 lb. fell to the earth. The latter was "dug up

[1] *The Scenery of the Heavens*, p. 137. To make the list of meteoric falls in Great Britain more complete I have added some falls not mentioned by Lockyer.

from a depth of 14 feet in stiff clay soil." A chemical examination of the smaller mass showed the metallic portion to consist of an alloy of iron, nickel, and tin.[1]

In 1885, near Mazapil, in Mexico, the appearance of a large fire-ball was followed by a loud explosion, and the fall of a number of stones. "About 800 lb. of stones, nearly two hundred in number, have been picked up in a region seven miles by four, a little east of the end of the meteor's path."

Professor Lockyer says: "The largest meteorites of which mention is made are those of Otumpa (province of Tucuman, South America), an iron weighing 30 tons; of Durango (Mexico), 19 tons; and of Cranbourne (Australia), now in the British Museum, which weighs over 3 tons. The Nejed iron, the largest which has been seen to fall, weighs nearly 130 lb."[2]

The general form of meteorites is fragmentary, indicating that they are the fractured portions of larger masses, burst asunder by the force of the explosion which generally accompanies these phenomena. In the case of the meteorite which fell at Butsura in 1861, pieces picked up at places three or four miles asunder could be actually fitted together to form the original mass!

Meteorites are usually covered by a black crust, clearly due to the intense heat developed by the mass in rushing through the earth's atmosphere with "planetary velocity," a velocity which, according to Lockyer, is sufficient to raise the air to a temperature of from 4000° to 6000° C.[3] The

[1] *American Journal*, July 1879.
[2] *The Meteoritic Hypothesis*, p. 20.
[3] *Ibid.*, p. 16.

highest recorded velocity of flight through the air is about 45 miles per second, or about double the orbital velocity of the planet Venus.

Meteorites are, however, only fused on their surface. Before they enter the earth's atmosphere they have, of course, the temperature of interstellar space. If the meteorite be large and its fall to the earth rapid, this original low temperature may be retained in its *interior* for some time after it reaches the earth. It is recorded that one of the large fragments of the Dhurmsala (India) meteorite which fell in 1860 "was found in moist earth half an hour or so after its fall *coated with ice.*"[1]

According to Lockyer the chemical elements most commonly found in meteorites are as follows :—

Hydrogen	Calcium
Iron	Aluminium
Nickel	Carbon
Magnesium	Oxygen
Manganese	Sulphur
Cobalt	Silicon
Copper	Phosphorus,

and "the following less frequently, or in smaller quantities" : —

Lithium	Chromium
Sodium	Tin
Potassium	Arsenic
Strontium	Antimony
Titanium	Chlorine

Nitrogen.

Of these only hydrogen, nitrogen, and carbon occur in an elementary condition."[2]

[1] Young's *General Astronomy*, Article 765.
[2] *The Meteoritic Hypothesis*, p. 23.

"The absolute absence of free quartz" from meteorites is remarkable, as this is one of the most widely diffused minerals known in terrestrial rocks. On the other hand, many of the meteoritic compounds are unknown on earth. For instance, we have compounds of sulphur and iron, sulphur and calcium, sulphur with calcium and titanium, and sulphur with iron and chromium, which are "new to our mineralogy." Various *alloys* of nickel and iron are also found.

Among the compounds common to meteorites and terrestrial rocks may be mentioned magnetic pyrites, magnetite, chromite, olivine, augite, anorthite, labradorite, etc. Of these olivine is one of the most usual substances met with in the "stones." In the "irons," iron, nickel, and magnesium are the principal constituents. Magnesium is also found in the "stones."

Meteorites also include a quantity of occluded hydrogen in the "irons," and carbonic acid in the "stones."[1] The gases obtained from the Lenarto meteorite were found to contain about 85½ per cent. of hydrogen.

In the "irons," or "siderites," the amount of iron varies from 80 to 98 per cent. and the nickel from 6 to 10 per cent. Sometimes, however, the nickel is found in much larger quantities; in one case amounting to "59 per cent., while the iron was only 37 per cent."[2]

From the presence of a mineral peculiar to meteorites, known as Daubréelite, Dr. Lawrence Smith "inferred a

[1] This view has, however, been called in question by Mallet. *The Meteoritic Hypothesis*, p. 27.

[2] *The Meteoritic Hypothesis*, p. 27.

common origin for two meteorites which fell four years apart."[1]

In his investigations on the spectra of metals found in meteorites Professor Lockyer made experiments at varying temperatures represented by the heat of the

Bunsen burner,
Oxy-coal-gas flame,
Electric arc,
Spark with jar,

the first being the lowest and the last the highest temperature.

In the case of magnesium he finds that of three well-known lines in the green part of the spectrum, known as b_1, b_2, and b_4, only two, b_1 and b_2, are seen in the flame spectrum, in which another line, "the remnant of a fluting, appears at wave-length 5210, so as to form a triplet." A line in the blue also appears, and the fluting at 500. In the spark spectrum the line at "5210 practically disappears and is replaced by b_4, the wide triplet thus giving way to a narrower one, b_1 and b_2 being common to both." "At the same time the line in the blue disappears and gives places to two new ones."[2] Lockyer finds that at the temperature of the Bunsen burner (as ordinarily used) the fluting at 500 "far eclipses the other parts of the spectrum in brilliancy." It is on the identity of this fluting (or rather its brightest edge) with the chief line in the spectrum of the nebulæ that the meteoritic hypothesis mainly depends. The question of this identity, which has been disputed by Lockyer's opponents, will be considered further on.

Lockyer finds that "in meteorites in which the quantity

[1] *The Meteoritic Hypothesis*, p. 23. [2] *Ibid.*, p. 39.

of iron is very considerable it is always the manganese that makes itself visible first, because its volatility is greater than that of iron."[1] The observations made with the oxy-coal-gas flame "gave in all about ten or a dozen lines belonging to the metals magnesium, iron, sodium, lithium, and potassium, and two flutings, one of manganese and one of iron." In the spectra of meteorites raised to the temperature of the electric arc the number of visible lines became so numerous that Lockyer had recourse to photography in order to register them. He says :—

"A photograph of the spectrum of the Oberukirchen meteorite, taken in this way, shows no less than 378 lines, of which 348 are due to iron. . . . Besides the iron lines the photograph also shows 16 lines of nickel, 3 of chromium, 1 of cobalt, 4 of manganese, 2 of titanium, and 4 unknown lines. It is also worth noting that this particular meteorite shows practically no sodium, although the nickel line, between the two D lines, is pretty bright."[2]

The spectra of meteorites at the temperature of the "quantity spark" without Leyden jar show "in all about twenty lines belonging to the metals magnesium, sodium, iron, strontium, barium, calcium, chromium, zinc, bismuth, and nickel, and four lines of unknown origin."[3]

At the temperature of the jar spark "a very great number of lines is visible." Lockyer, however, considers that, for the purpose of his inquiry, these high-temperature spectra are not of so much importance as those at low temperatures.

Most of Lockyer's experiments were made on "undoubted meteorites," fragments of which were obtained from the British Museum.

[1] *The Meteoritic Hypothesis*, p. 53. [2] *Ibid.*, p. 55. [3] *Ibid.*, p. 58.

Lockyer's general conclusions with reference to these experiments are :—

(1) "That only the lowest temperature lines of Magnesium, Sodium, Iron, Chromium, Manganese, Strontium, Calcium, Barium, Potassium, Lead, Bismuth, and Nickel are seen in the meteorites under the various conditions. They are not all visible in one meteorite or under one particular condition.

(2) "That in the case of Magnesium the line most frequently seen is the remnant of the fluting at 500, while in a photograph the main ultra-violet line recorded is the one at 373, previously recorded under those conditions by Messrs. Liveing and Dewar. In the quantity spark other lines are seen, notably b_1, b_2, b_4, and 521. The line at 500 was considerably brightened when the number of cells was reduced, thus showing it to be due to some molecule which can exist best at a low temperature.

(3) "That in the case of Manganese the only line visible at the temperature of the Bunsen burner, 5395, is the only line seen in the meteorites, with the exception of one in the violet at 403.

(4) "That the lines of iron seen in the meteorites are those which are brightest when wire gauze is burned in the flame ; chief among these lines are 579, 5268, 4383, and 6024."

Professor Lockyer then proceeds to show the identity of origin of luminous meteors and falling stars with meteorites. With reference to the light emitted by shooting stars, which are probably *very* small bodies, "Professor Herschel has calculated that a single grain moving at the rate of 30 miles a second represents a dynamical energy of 55,675 foot pounds." A large portion of this energy is of course converted into light and heat.

The spectra of meteors and shooting stars show the sodium line, and the bright *b* line of magnesium, and, according to Konkoly, the lines of marsh gas. It appears from the observations of Professors Herschel, Newton, and Secchi that shooting stars first become visible at an average

height of 72·7 miles, and disappear at a height of 51·5 miles.[1]

Discussing the observations of the aurora and its spectrum, Lockyer attempts to prove that the phenomenon is due to meteoric dust in the "higher reaches" of the atmosphere. He identifies the characteristic line of the aurora —frequently the only line visible—with "the remnant of the brightest manganese fluting at 558."

After considering the probable identity of other lines seen by different observers in the auroral spectrum he says :—

"I think it will be granted that, after what has preceded, there is strong evidence of an intimate relation between the spectrum of the aurora and the spectra of meteorites, which leads to the conclusion that the upper reaches of the atmosphere contain particles of magnesium, manganese, iron, and carbon."[2]

The objections which have been advanced against this conclusion will be considered further on.

Lockyer shows that traces of meteoritic dust are visible in oceanic deposits dredged up by the *Challenger* Expedition.

In some very interesting chapters on meteors and meteoric showers, Lockyer discusses their relation to comets, a relation which has been chiefly established by the researches of Professors Herschel, Newton, and Schiaparelli. He says: "We must picture a comet as a loose, transparent, illuminated, free-moving swarm of small solid granules suspended in empty space,"[3] and "that the head of a comet is merely the denser part of the swarm."[4]

[1] *The Meteoritic Hypothesis*, p. 67.
[2] *Ibid.*, p. 97.
[3] *Ibid.*, p. 144.
[4] *Ibid.*, p. 146.

Having described the appearances presented by comets at different distances from the Sun, Lockyer discusses the theories which have been advanced to account for the phenomenon of the tail. It appears that Kepler was the first to suggest that the tail was due to an impulsive force resident in the Sun, an hypothesis which was accepted by Newton, Euler, and Laplace. Olbers considered that the repulsion was due to electrical action, and this theory, adopted by Roche and Bredechin, seems to be now almost universally received. M. Roche determined mathematically "the surface on which the gravity of a small particle was *nil* in consequence of the solar and cometary attractions. This is called the limiting surface."[1] "The limiting surfaces which Roche's calculations require are so very like some of the surfaces actually observed in the head of a comet, where they can be best seen, that it is suggested that the movement of the particles takes place in the precise direction where they would flow according to M. Roche's mathematical investigations.[2] . . . M. Roche therefore considers the existence of a repulsive force which counterbalances solar attraction established by his researches."[3]

Bredechin divides the tails of comets into three distinct types. In the first type the tails are long and straight—like that of the great comet of 1861. In these he computes that the small particles composing the tail are shot out from the nucleus with a velocity of about 14,000 or 15,000 feet per second. In the second type the velocity is about 3000 feet a second. In this case the forces of attraction and repulsion are nearly balanced, and the tail is plumy

[1] *The Meteoritic Hypothesis*, p. 160. [2] *Ibid.*, p. 163. [3] *Ibid.*, p. 164.

and gently curved. In the third type the velocity of repulsion falls to only 1000 feet per second. The tails are short and strongly curved, and the repulsive force is only about one-fifth of the Sun's attractive force. Bredechin thinks that tails of the first type are probably composed of hydrogen, those of the second of hydrocarbons, and those of the third type of the vapour of iron and heavier metals.

Lockyer then proceeds to discuss the character of the spectra shown by comets at different distances from the Sun. He says :—

"In the comets of 1866 and 1867 when they were observed away from the Sun, only one line was seen near wave-length at 500. . . . It is probable also that one of the bands mentioned by Konkoly in his observations on the Great Comet (*b*) 1882 (date of periastron passage 17th September) on the 1st November was this same line which lies at or near the position of the low temperature fluting of magnesium at 500. By that date the D line of sodium and the carbon flutings had passed their maximum intensity and had begun to fade out. The same line was also probably seen in Coggia's Comet by Vogel (III. 1874), who records a bright line at about 499, when the comet was yet a month from perihelion, and when, therefore, the appearance of the low temperature characteristic of the magnesium spectrum would be expected."[1]

He finds also that comets at a distance from the Sun show lines corresponding to those of carbon at a low temperature.

In comets at the mean distance from the Sun Lockyer finds evidence of hot carbon, magnesium, manganese, and lead.

In the spectra of comets immediately preceding the perihelion passage he finds hot carbon, "the radiation of

[1] *The Meteoritic Hypothesis*, pp. 171, 172

manganese replaced by absorption," lead absorption, and also "cool carbon absorption masking the radiation of hot carbon."

In the spectra of comets *close* to the perihelion he finds evidence of the magnesium line *b* and the carbon lines near wave-length 426—indicating a high temperature. He also finds "line absorption" in comet Wells and the great "September comet" of 1882. In the former there was evidence of the presence of iron, sodium, manganese, carbon, and magnesium, and in the latter the same elements with the addition of lead.

With reference to Coggia's comet of 1874, Lockyer says: "While ten minutes' exposure of a photographic plate gave no image of the comet, the faintest of the seven chief stars in the Great Bear gave an impression in two minutes."[1]

Professor Lockyer thus sums up the sequence of the spectral changes in comets:—

"The first visible stage in the spectrum of a comet is that in which a single line is visible; relying on the position given by Dr. Huggins this may with great probability be attributed to the radiation of magnesium. The next is that in which this line is replaced wholly or partially by the spectrum of cool carbon. The line 521, also seen in the spectrum of magnesium, is then added, and cool carbon is replaced by hot carbon. The radiation of manganese (558) and sometimes of lead (546) follow. Absorption phenomena next appear; manganese 558 and lead 546 being indicated by their masking effects upon the citron band of carbon. The absorption band of iron is also sometimes present at this stage, at which also the group of carbon flutings, which I have called carbon B, probably also makes its appearance. As the temperature increases still further, magnesium is represented by *b*, and lines of iron appear; this takes place when the comet is at or near perihelion. At this point the repellent action

[1] *The Meteoritic Hypothesis*, p. 205.

of the Sun upon the comet is most effective, and if the vapours are driven off in the line of sight with sufficient velocity, the bright lines will suffer displacement. A double set of phenomena will thus be presented: there will be radiation lines of one wave-length from the vapours thus driven off, and the absorption lines of a different wave-length from the vapours surrounding the meteorites in the head.

"As the comet recedes from perihelion, these changes take place in inverse order. . . .

"This complete sequence has never been observed in any single comet, but it has been continued in some comets where it has been left off in others."[1]

Comparing the spectra of comets and auroræ he finds them very similar, and thinks the view that the aurora spectrum "is produced by meteoric dust in our atmosphere is thus greatly strengthened."[2]

Lockyer then proceeds to develop his theory that the light of comets is chiefly due to collisions between the component meteorites. With reference to the observed transparency of comets he says: "To enable the comet to reduce by one-tenth the light of a star seen through it, it would require to be 300 miles thick, supposing the stones to be 1 inch cube and 20 feet apart."

Assuming the total mass of a comet to be $\frac{1}{1000}$ that of the earth and its volume 250 times greater, he says that if we assume the stones to be ten inches cube, their average distance apart would be about 17 feet. "By making the stones larger, and thus increasing the distances between them, the luminosity would be retained, while at the same time the swarm would be sufficiently transparent. It thus seems to suit the hypothesis better if we regard the separate stones to be greater than 10 inches cube."[3] The hypothesis

[1] *The Meteoritic Hypothesis*, pp. 215, 216, 217. [2] *Ibid.*, p. 225.
[3] *Ibid.*, p. 229.

referred to is that of Professor Tait; but Lockyer says: "The mass of individual comets probably never exceeds $\frac{1}{5000}$ of that of our globe. The meteorites composing them must therefore be very far apart, seeing that this small mass is distributed through spaces millions of miles in extent."[1]

Part of a comet's light may, he thinks, be due to "external collisions." He says:—

"But it is not unnatural to suppose that a meteoritic swarm moving through space and ploughing its way through a meteoritic plenum will encounter other meteorites, and from this cause the number of external collisions will depend, in the first place, upon its size. If the earth, some 8000 miles in diameter, encounters 400,000,000 daily, a comet as large as the Sun, as some of them are, will naturally encounter an enormous number."[2]

The remarkable variations of brightness observed in the Pons-Brooks comet of 1883, and Sawerthal's comet of 1888, seem to favour this idea of collisions with external swarms. Lockyer thinks that the great increase of brilliancy of comets near perihelion may partly be due to collisions which take place "between the meteorites of the comet and those which occupy the outer cooler regions of the Sun," and he thinks that "collisions between individual meteorites would not retard the motion of a comet as a whole."

With reference to the disputed question of the origin of comets, Lockyer favours the view that both shooting stars and comets did not originate within the Solar System, but are of cosmical origin—that is, that they have been drawn into our system from external space by the force of gravitation. Professor Kirkwood has shown that

[1] *The Meteoritic Hypothesis*, p. 229. [2] *Ibid.*, p. 232.

cometary perihelia show a "tendency to crowd together about the direction of the Sun's journey in space."[1] Mr. Monck, however, doubts the correctness of this conclusion. It was shown by Leverrier that the Leonid swarm of meteors, which produces the great meteoric display every thirty-three years about November 14th, "possibly owed its existence as a member of our system to the attraction of Uranus." This probably took place about A.D. 126.

Lockyer next discusses the probable existence of meteoric swarms in interstellar space. He gives an interesting historical notice of Sir William Herschel's observations of nebulæ and the different classes into which these wonderful objects were divided by that great astronomer. Having referred to the observations of Sir John Herschel and Lord Rosse, and the spectroscopic discoveries of Dr. Huggins, he proceeds to discuss the spectra of the nebulæ, and the probable identity of the bright lines observed with the lines of terrestrial elements. As is well known, the spectra of the *true* nebulæ consist of a very faint continuous spectrum, crossed by one, two, three, or four bright lines.[2]

One of these bright lines is certainly due to hydrogen. Another of these lines—that near wave-length 500—is always considerably brighter than the others, and is known as "the chief nebular line." This line was at first supposed to coincide in position with one of the lines in the spectrum of nitrogen, but this is now known to be an error. It lies near the nitrogen line (or rather double line), but is quite

[1] *The Meteoritic Hypothesis*, p. 249.

[2] In the spectrum of the "great nebula" in Orion other bright lines are visible. The complete hydrogen series of lines were photographed by Dr. Huggins in 1890.

distinct from it. It also lies near a line of lead, but is distinct from that line also. According to Lockyer it is identical with a line near 500, seen in the spectra of the comets of 1866, 1867, 1882, and in Coggia's comet of 1874, when these comets were at some distance from the Sun. With reference to the spectra of comets and nebulæ he says :—

"Other flutings and lines again are special to comets and others to nebulæ. Thus there are practically no indications of hydrogen in comets, although the hydrogen lines are amongst the brightest in nebulæ. Again the lines 447, 479, 495, 509, 554, and 5872 are seen in nebulæ, but not in comets. On the other hand, the cool carbon flutings and the fluting at 568 are seen in comets, but not in nebulæ. Most of these apparent discrepancies are explained by a consideration of the differences in the conditions of comets and nebulæ. It must be remembered that in the case of comets there is an action which repels the vapours produced by collisions, and the vapours first affected will, of course, be those which are less dense. Hydrogen will thus be repelled from the comets, whilst the denser vapours of magnesium and carbon remain. There is then a good reason why hydrogen lines should *not* be seen in cometary spectra. As there can be no such repulsion in the sparse swarms which constitute nebulæ, hydrogen lines are seen in them."[1]

With reference to the actual position of the "chief nebular line" near wave-length 500, Lockyer maintains that it coincides *exactly* with the brightest edge of the magnesium fluting—that is, the least refrangible (on the red side) of the group of lines which constitute the fluting. This line was first identified by Dr. Huggins in 1864 with one of the lines of nitrogen. In 1874 observations seemed to show that it coincided with a line of lead. Later observations, however, proved that it does not coincide with either of

[1] *The Meteoritic Hypothesis*, p. 291.

these lines. Observations by Lockyer in 1887 with a spectroscope of small dispersion (one prism of 60°) seemed to show that it coincided with the edge of the magnesium fluting. The dispersion used was, however, clearly insufficient to decide so delicate a point. Using a higher dispersion, viz., a Steinheil spectroscope with three and four prisms, and a Cooke spectroscope of sixteen prisms attached to a 30-inch reflector, he again found the nebular line to be coincident with the edge of the magnesium fluting. To avoid some difficulties attending these experiments he then employed a siderostat, a 10-inch object glass, and a Steinheil spectroscope, and, observing the spectrum of the Orion nebula, he arrived at the following conclusion, with which his assistants agree :—

"The observations have left no doubt in my mind as to the coincidence of the chief nebula line with the magnesium fluting, under such conditions that at the same time the coincidence of the F line of hydrogen with the third nebula line was demonstrated. Lieutenant Bacon and my assistants concur in this view."

He then discusses the appearance of the nebular line, and the evidence in favour of its being a fluting and not a line. He thus describes the appearance of the magnesium fluting at 500 :—

"The compound fluting of magnesium near λ 500 is very similar to that of carbon. It consists of a series of bright lines of gradually diminishing brightness and increasing distances apart towards the more refrangible end, and each has a fringe[1] *on the more refrangible side.* The first maximum (the least refrangible) is brighter than the

[1] "With higher dispersion the fringes break up into series of fine lines very close together." *The Meteoritic Hypothesis*, p. 313.

others, and the fringe close to it is brighter than the second maximum: hence when "the remnant of the magnesium fluting near 500" is referred to, the first maximum, with that portion of its fringe which is brighter than the second maximum, is meant." [1]

He then quotes the earlier observations of the nebular line, which show that it was seen nebulous at the edges by several observers, including Dr. Huggins. Lockyer's own observations of this line in the Orion nebula with the 30-inch reflector show that "whilst the F line is thickened equally on both sides, the chief line thickened only on the more refrangible side." [2] . . . "In still more recent observations with a siderostat the chief line was noted by Mr. Fowler and Lieutenant Bacon to have a decided fringe on the more refrangible side."

Lockyer argues that "high dispersion is not so likely to show the fluted character of the chief line as low, for the more the fringe is dispersed the fainter it must become"; and he finds that the spectrum of burning magnesium when its light is reduced by neutral tint-glass shows the fluting in question with an appearance very similar to that of the chief nebular line in the Orion nebula. Dr. Huggins' more recent observations of the nebular line will be given further on.

From his spectroscopic results Lockyer concludes that "nebulæ are really swarms of meteorites or meteoritic dust in the celestial spaces. The meteorites are sparse, and the collisions among them bring about a rise of temperature sufficient to render luminous some of their chief constituents." [3] He considers that "the nebula in Andromeda is more condensed than that in Orion, for the reason that

[1] *The Meteoritic Hypothesis*, p. 314. [2] *Ibid.*, pp. 317, 318. [3] *Ibid.*, p. 322.

its spectrum resembles a comet when it is known to be more condensed than at aphelion."[1] He thinks that the rapid increase of light observed in the *novæ* or temporary stars indicates that their sudden increase of brilliancy and subsequent rapid decrease is due to the incandescence of *small* masses of matter, a consideration which strengthens the view that these so-called "stars" consist of clouds of meteoric stones.

With reference to the probable origin of the various forms observed in the nebulæ, Lockyer supposes that "streams or sheets of nebulous material, invisible if undisturbed, may encounter others, and in this way luminous patches of undefined shape may be produced by motions and crossings and interpenetrations, the brighter portions being due to a greater number of collisions per unit of volume." He explains the appearance presented by the planetary nebulæ by supposing collisions to occur along the sphere of intersection of the meteorites moving in elliptic orbits round a common centre.

In some cases these collisions would start the meteors in new orbits in the interior of the first shell, thus giving rise to a smaller collision shell and the appearance of a globular nebula with a bright central luminosity. If these inner orbits are very elongated, the intersection shell will become nearly a point, thus producing the appearance of a "nebulous star." He explains the appearance presented by those wonderful objects the "spiral nebulæ" by supposing the original swarms composing the nebulæ to be invaded from without "by other swarms which feel its attraction and have their paths deflected. . . . If they enter in excess

[1] *The Meteoritic Hypothesis*, p. 325.

from any direction, we shall have the appearance of broken rings or spirals." [1]

This seems to me a rather weak point in the theory, for these spiral nebulæ certainly suggest a rotating mass, gradually breaking up into rings by the force of the rotation. Lockyer explains the appearance of those nebulæ which resemble comets in shape by "either a very condensed swarm moving at a very high velocity through a sheet of meteorites at rest, or the swarm at rest surrounded by a sheet all moving in the same direction." [2]

He next proceeds to discuss the classification of the stars and their spectroscopic division into types. This classification will be found in the chapter on "Celestial Chemistry" in the present volume (Chapter VII.).

According to Lockyer's "new views" the stars of Vogel's Class III. *a*—which includes many variable stars—are not suns like ours, but closely resemble comets, and probably consist of swarms of meteorites, "clouds of incandescent stones." However this may be, he justly remarks "how a body constituted in any way like the Sun could change its magnitude from the thirteenth to the sixth every year or so, or change its hydrogen lines from bright to dark once a week, passes comprehension; and the more closely a 'star' resembles the Sun the less likely are such changes to happen." [3]

Comparing the spectra of certain comets with those of stars showing bright lines, he concludes that these stars "are nothing more than swarms of meteorites a little more condensed than those which we know as nebulæ." [4]

[1] *The Meteoritic Hypothesis*, p. 336.
[2] *Ibid.*, p. 338.
[3] *Ibid.*, p. 353.
[4] *Ibid.*, p. 356.

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All these conclusions rest of course on the supposed coincidence of certain lines in the spectra of comets, nebulæ, and stars with bright lines and flutings, a coincidence which has been disputed by other observers. Relying, however, on the accuracy of his experiments Lockyer proposes a "new grouping of cosmical bodies." He supposes some of these bodies to be increasing in temperature, while others —like our own Sun—are cooling.[1] He represents this hypothesis graphically by a temperature curve. On the rising branch of the curve he places at the lowest temperature the nebulæ and stars with bright lines, but without hydrogen. Above these come nebulæ with hydrogen, and stars of Class II. *b*. Then stars of Class I. *c*, Class III. *a*, some of Class II. *a*, and at the summit of the curve stars of Class I. *a*, like *a* Lyræ, representing the highest known temperature. On the descending or cooling branch of the curve he places the stars of Class II. *a*, which closely resemble our Sun, and stars of Class III. *b*. These he afterwards divides into groups, forming the following classification :—

"GROUP I.—Radiation lines and flutings predominant. Absorption beginning in the last species.

GROUP II.—Mixed radiation and absorption predominant.

GROUP III.—Line absorption predominant with *increasing* temperature. The various species will be marked by increasing simplicity of spectrum.

GROUP IV.—Simplest line absorption predominant.

GROUP V.—Line absorption predominant with *decreasing* temperature. The various species will be marked by decreasing complexity of spectrum.

[1] Lockyer's curve rests on this assumption, but it should be stated that ome astronomers doubt that the Sun is really cooling.

Group VI.—Carbon absorption predominant.
Group VII.—Extinction of luminosity." [1]

Of these groups he places I., II., and III. on the rising branch of the temperature curve, IV. at the top, and V., VI., and VII. on the descending or cooling branch.

He then proceeds to divide these groups into sub-groups and species, according to the character of the spectra shown by the various objects included in each group. He gives a detailed discussion of the bright-line spectra shown by the stars γ Argûs, Argelander-Oeltzen 17,681, Lalande 13,412, the Wolf-Rayet stars in Cygnus, and γ Cassiopeiæ.

The spectrum of γ Argûs, as observed by Copeland, Ellery, Lockyer himself, and Respighi, he considers "due to low-temperature sodium and iron, and to carbon flutings or a bright continuous spectrum."

In A.-Oe. 17,681, the spectrum of which was observed by Pickering and Vogel, he finds hot carbon, manganese, and iron bright lines on a continuous spectrum.

In Lalande 13,412, also observed by Pickering and Vogel, he finds "a continuous spectrum from the meteorites, and carbon bands, one of them appearing beyond the continuous spectrum in the blue as a bright band; bright lines of hydrogen, manganese, and iron being superposed on both."

In the 1st Wolf-Rayet star in Cygnus (DM + 35°, 4001), observed by Wolf, Rayet, and Vogel, he finds a faintly continuous spectrum with hot carbon, and "the strongest low-temperature lines of manganese, iron, and cadmium, with a strong manganese fluting, and the green sodium

[1] *The Meteoritic Hypothesis*, pp. 381, 382.

line appear on the continuous spectrum. There is no absorption of any kind."[1]

In the 2nd star in Cygnus (DM + 35°, 4013), also observed by Wolf, Rayet, and Vogel, he finds a continuous spectrum with bright carbon, and bright lines of iron, manganese, sodium, and some as yet undetermined substance giving a line at 636, which, however, was observed "as a bright line in the Limerick meteorite at the temperature of the oxyhydrogen blowpipe."

In the 3rd Wolf-Rayet star in Cygnus (DM + 36°, 3956) he finds a continuous spectrum with "the low-temperature manganese line, and the strongest manganese fluting; the low-temperature iron line, the green sodium," and the 636 line of the Limerick meteorite.

In γ Cassiopeiæ—the spectrum of which has been observed by Secchi, Vogel, Huggins, Gothard, Konkoly, and Sherman—he finds evidence of a continuous spectrum with bright lines and bands of hot carbon, hydrogen, manganese, iron, magnesium, hydrocarbon, the line 636 of the Limerick meteorite, and a line at 463 of unknown origin, which was seen "bright in R Geminorum, but has up to the present not been detected in any experiment with meteorites."[1]

From recent observations of these stars Dr. Huggins finds, however, that the bright lines attributed by Lockyer to carbon do *not* coincide with the carbon bands.

With reference to the sequence of temperature in the Cygnus stars, Lockyer concludes that "1st Cygnus is the coolest, 2nd Cygnus ranks next above it in temperature, and 3rd Cygnus is the hottest of the three."[1]

[1] *The Meteoritic Hypothesis*, Chap. XXXV.

From photographs of the region in Cygnus containing the Wolf-Rayet stars, Professor Pickering discovered four other stars with bright lines in their spectra. Among these is the star P(34) Cygni—the so-called Nova of 1600. With reference to its spectrum Lockyer says :—

"In addition to the hydrogen lines there is a bright line in P Cygni, the wave-length of which I have found to be about 447. This appears to be coincident with Lorenzoni's *f* of the chromosphere spectrum, and it is also seen in the spectrum of the Nebula in Orion. In all three cases it is associated with the line D_3.'

Lockyer then proceeds to discuss Dunér's observations of the bands and flutings visible in stars of the third type.[2] He shows that the dark bands visible in the spectra of these stars may, in some cases at least, be partly due to contrast with adjoining bright flutings. He identifies some of the bright spaces between the bands, seen by Dunér, with the radiation flutings of carbon. These lie near Dunér's bands 8, 9, 10, and 11. He also finds indications of *absorption* flutings and bands due to iron, manganese, lead, barium, magnesium, and chromium. He argues that the differences in the spectra observed in these stars may be mainly accounted for by differences in the amount of interspace in the meteoric swarms which constitute them. By the term "interspace" he denotes "the relative areas of space and meteorite in a section of the swarm at right angles to the line of sight." With a reduction of the spacing he contends that "(1) the temperature must increase, (2) the carbon spectrum must first get more intense, and then diminish afterwards as the

[1] *The Meteoritic Hypothesis*, Chap. XXXV.

[2] *Sur les Étoiles a Spectres de la Troisième Classe* (Stockholm, 1885).

spaces, now smaller, are occupied by vapours of other substances, (3) the continuous spectrum of the meteorites must increase, (4) the spectrum must gradually get richer in absorption bands."[1]

Discussing Dunér's individual observations he finds that the *extreme* stages of spacing (or degrees of condensation of the meteorites) are indicated by (*a*) "the first stage, representing almost a cometic condition of the swarm before condensation has begun,"[2]—among Dunér's stars of this stage referred to by Lockyer there are many variable stars,—(*b*) "the last stage before all the bands fade away entirely." Among the stars of this stage referred to by Lockyer (p. 418) there are no known variable stars. In stars with discontinuous spectra, like *α* Herculis, R Hydræ, and X Herculis, he considers that the meteorites "are wide apart, though not at their widest." In other cases the spectra are not discontinuous, "and the flutings, instead of being black, are pale." Here he thinks "the average distances between the meteorites have been reduced."[3] This stage includes the variable stars T Ursæ Majoris and R Camelopardali.

Proceeding to the consideration of his Group III. he discusses the spectral characteristics which differentiate Group II. from Group III. Defining Group II. as the "mixed fluting" group, he draws the line between the groups at the stage where carbon radiation ceases. He considers that *α* Ceti is "the most advanced Group II. star of which observations have at present been made."[4]

[1] *The Meteoritic Hypothesis*, p. 417. [2] *Ibid.*, p. 418. [3] *Ibid.*, p. 420.
[4] *Ibid.*, p. 435. The spectrum of *α* Orionis seems to be also a transition spectrum.

In the spectra in Group II. he finds the following general sequence from the earlier to the later species:—

"(1) The hydrogen lines are thin. D is thicker than *b*. The iron fluting is faint. 499, E, 5327, 540, 568 and 579 are thin. 546 and 558 are fairly thick.

"(2) The hydrogen lines are thicker. F, D, and *b* are equally thick. E, 5327, 540, 579, and 499 are much thicker, being nearly as strong as F. The iron fluting has gone.

"(3) The hydrogen lines are very much thicker than the other lines. D and *b* are equally thick. E is nearly as strong as *b*, while the other lines are fainter.

"(4) The hydrogen lines are very broad, while all the remaining lines are exceedingly faint."[1]

The stars *ι* Aurigæ and *α* Tauri (Aldebaran) belong to the earlier species, and *β* Persei (Algol) and *α* Aquilæ (Altair) to the later species. The greater width of the hydrogen lines in the latter stars indicate a higher temperature.

Stars in Group IV., like *α* Lyræ (Vega) and Sirius, in which the hydrogen lines are wider still, represent the point of maximum temperature among cosmical bodies.

In Groups III. and V. the former is supposed to include bodies in which the temperature is increasing, and the latter—which includes our own Sun—bodies in which the temperature is decreasing. The criterion between these two classes—which have very similar spectra—is, according to Lockyer, found in the relative intensities of certain lines. There is a "double line about wave-length 540, which, with the two iron lines E (5268) and 5327, forms a trio." Now "the double" in Group V. is considerably weaker than E, whereas that in Group III. is very nearly

[1] *The Meteoritic Hypothesis*, p. 441.

as strong as E. The appearance presented to the eye by the real trio in stars of Group III. is accordingly very different from that presented by the three lines in stars of Group V."[1] Again there is a line near wave-length 499, which in some stars is very strong, but is "only seen as a very faint line in Capella, Arcturus, or the Sun, and is consequently an important criterion."[1] Two lines at 579 and 568 also seem to be special to Group III., at least they are much stronger in these stars than in those of the solar type. By these criteria it is now possible to divide the stars of Vogel's Class II. *a* into two groups.

Group VI., which includes Vogel's III. *b* stars (Secchi's 4th type), is defined, according to Lockyer, "by enormous carbon absorption, which is the real origin of the inversion of the dark spaces first pointed out by Secchi, although he missed its significance." He thinks that "the blood-red stars are approaching the extinction of their light, chiefly by continuous absorption, strongest at the blue end."

Group VII. includes dark bodies, which of course give no spectrum, and are therefore invisible to us (at least, those which may exist in interstellar space) either with the telescope or spectroscope.

Lockyer then proceeds to discuss the binary and multiple star systems. He considers that in most cases binary stars originally existed in the condition of double nebulæ, although in some of them it is possible that the companion was added to the system in the same way that periodical comets have been occasionally added to our own.

[1] *The Meteoritic Hypothesis*, p. 443.

The colours of the objects included in Lockyer's Groups are, as a general rule, as follows :—

"Group I.—Blue, greenish-blue, white, or pale grey.
Group II.—Yellowish-red.
Group III.—Yellow to white.
Group IV.—Bluish-white.
Group V.—White to yellow.
Group VI.—Reddish-yellow to blood-red.
Group VII.—Dark bodies." [1]

Lockyer thinks that the binary stars probably originated as follows :—

1. *Magnitudes*, colours, and spectra of the components identical. Both originated either "in the same nebulosity with two condensations, or in a double nebula."

2. *Magnitudes nearly equal*, but colours and spectra different. Possibly "the one with the most advanced spectrum has the smaller mass."

3. *Magnitudes very unequal.* Probably the fainter component has the smaller mass ; "and if it is proportionately in advance as indicated by the spectrum, or colour, we may regard both components as having had a common origin. If the smaller one be less advanced than the larger one, we have to regard it as a later addition to the system."

"*If the two stars are of equal mass*, and revolve round their common centre of gravity, they have in all probability done so from the nebulous stage, and therefore they will have arrived at the same stage along the evolution road, and their colours and spectra will be identical."

"*If, however, the masses are very different*, then the smaller mass will run through its changes at a much

[1] *The Meteoritic Hypothesis*, p. 448.

greater rate than the larger one. In this way it is possible that the stars seen so frequently associated with globular nebulæ may be explained ; while the nebula with a larger mass remains still in the nebulous condition, the smaller one may be advanced to any point, and may indeed even be totally invisible (Group VII.) while the parent nebula is still a nebula."[1]

Lockyer then divides into classes the binary systems included in Chamber's edition of *Smyth's Bedford Catalogue*. In Class I. he includes those "in which the magnitudes and colours of the components are almost identical." Among these he includes 32 Orionis, magnitudes 5 and 7, ζ Ursæ Majoris 4, 5½, ϵ Ophiuchi 7, 9, ξ Cephei 5 and 7 ; but it can hardly be said that the magnitudes of these are "identical."

In Class II. he includes those of "equal magnitude and similar colours." In Class III. he groups those of "equal or nearly equal magnitudes, one star being Blue" ; but here again he includes stars like 49 Piscium, magnitudes 7, 10½, ι Leonis 4, 7½, ξ Boötis 3½, 6½, 70 Ophiuchi 4½, 7, 33 Pegasi 6½, 10,[2] which are certainly *not* of "nearly equal magnitude." Indeed, observers of double stars would speak of them as "rather unequal." In his Class IV. Lockyer includes doubles of "very unequal magnitudes, the smaller star being Blue." It seems doubtful, however, that *all* these stars with faint companions are really binary. Class V. includes pairs of "unequal magnitudes, the fainter star being Red."

[1] *The Meteoritic Hypothesis*, p. 450.

[2] A difference of 3½ magnitudes implies that the brighter component is 25 times brighter than the companion.

With reference to ζ Herculis, which he cannot place in any of the above classes, Lockyer thinks that possibly "we have here to deal with an added companion."

Lockyer next proceeds to suggest, in accordance with his theory, a probable cause for the variability in light and colour observed in the variable stars. In an introductory chapter he gives an interesting historical account of the discovery of Mira Ceti, χ Cygni, Algol, and β Lyræ, and the theories which have been advanced to account for their variability. In the next chapter he develops his own theory, based on the meteoritic hypothesis of the constitution of cosmical bodies. In the case of the regular variables he considers that the variation in light "is caused by the revolution of one swarm or body round another (or their common centre of gravity)." "In the case of the revolution of one swarm round another, an elliptic orbit is assumed, and the increase of light *at maximum* is produced by collisions among the meteorites at periastron. In the case of the revolution of a swarm round a condensed body, the increase of light *at maximum* is produced by the tidal action set up in the secondary swarm."[1]

In the case of irregular variability he considers the variation to be "caused, (*a*) by the revolution of more than one swarm or body round another (or their common centre of gravity); or (*b*) by the interpenetration of meteoritic sheets or streams. In the case of the revolution of more than one swarm round another in elliptic orbits the irregular maxima are caused by difference of period and periastron conditions."

This seems a very plausible hypothesis, but it is of

[1] *The Meteoritic Hypothesis*, p. 475.

course open to grave objections on mechanical principles. In the case of great variation of light—six to eight magnitudes—he supposes the orbit of the revolving swarm to be very elliptical. With less variation the orbit will be an ellipse of smaller eccentricity, and when the ellipse becomes nearly a circle "the smaller swarm will never be entirely out of the larger one, and at periastron the number of collisions will not be very greatly increased."

He gives a light curve of Mira Ceti, but falls into an inaccuracy with reference to its magnitude at minimum. He says "it descends to the tenth, and so far as observations with ordinary instruments go, it is invisible. . . . What happens to the light of the star below the tenth magnitude it is impossible to say."[1] Now Schmidt found the minimum magnitude to be 9·5, but Schönfeld states that he has never seen it fainter than the distant companion, or 9·1, and that it is usually somewhat brighter.[2] At the minimum of 1874 it was 8·6, according to Schönfeld. It thus appears that Mira is never so faint as 10th magnitude.

Lockyer accepts the eclipsing satellite theory of Algol, and indeed this hypothesis has been practically proved by recent spectroscopical observations. The light variation, however, does not amount to so much as two magnitudes, as shown in Lockyer's light curve (p. 486). Professor Pickering's photometric observations show that the total variation very little, if anything, exceeds *one* magnitude, and this is confirmed by my own eye estimations and those of other observers. Some observers, however, make the variation about 1·5 magnitude, but it is certainly not greater

[1] *The Meteoritic Hypothesis*, p. 484.

[2] See my first *Catalogue of Known Variable Stars*, pp. 167, 171.

than this. It may be stated here that Herr J. Plassmann, the well-known German astronomer, has recently announced his discovery of a secondary minimum in the light of Algol and λ Tauri. This occurs about midway between two principal minima. The most probable explanation of a secondary minimum in an Algol star—if it exists—would seem to be that the satellite has some inherent light of its own which is cut off when it passes *behind* the disc of the primary star.

No change occurs in the spectrum of Algol during the course of its light variation, but in the case of Ceraski's Algol star U Cephei a considerable change in the spectrum has been observed at minimum. Professor Pickering finds that in this latter case the eclipse must be a total one, and that consequently the satellite must have some inherent luminosity. From the change in the spectrum Lockyer concludes that "probably the companion has an absorbing action of some kind on the light of the central star passing through it or its surroundings."

With reference to the variability of stars in Group VI. (Vogel's III. *b*) Lockyer thinks "the variation would seem to be due to swarms of meteorites moving round a *dim* or *nearly dark* body, the maximum light occurring at periastron, when the tidal action in the swarm is greatest; in consequence of this dimness the addition of the light of what we, with our solar conditions, should term a large comet would make a great difference in the total radiation."[1]

He then gives tables of variable stars arranged according to the character of their spectra, from which it appears that the greater number of variables are found among those stars of the third type in which the bands are "wide and strong."

[1] *The Meteoritic Hypothesis*, p. 488.

He next tabulates the known variables, having spectra of the third type, according to length of period, the details respecting amount of variation and length of period being derived from my *Revised Catalogue of Variable Stars*, and the colours of the stars from Chandler and Dunér. Chandler found that the longer the period of variation the redder the tint, but Lockyer finds that this relation between colour and period "is only a general one."

According to Lockyer's hypothesis the bright lines of hydrogen "might be expected to make their appearance at maximum, accompanying the greatly increased intensity of the carbon flutings." Bright lines of hydrogen have been observed by Espin in R Cygni and Mira Ceti in 1888, and in R Leonis, R Hydræ, χ Cygni, R Andromedæ, and S Cassiopeiæ in 1889. These bright lines were also photographed in the spectra of Mira by Pickering in 1886.[1] Lockyer finds that the carbon bands at 517 and 546 also brightened in the spectra of Mira near maximum in October 1888, and that "in variable stars of this class the proof is now complete that the increase of luminosity is accompanied by cometary conditions, and that it is due to the increased radiation of carbon." This "proof" of course rests on the supposed identity of the bands in the spectrum of Mira with those of carbon. Lockyer adds :—

"These observations of Mira, and others which Mr. Fowler and myself have made on stars with Bunsen comparisons, entirely justify the conclusions drawn by Dr. Copeland from his work on U Orionis (when it was thought to be a Nova) that bright flutings of carbon were in question in that star, although that conclusion has been contested."[2]

[1] *The Meteoritic Hypothesis*, p. 505. [2] *Ibid.*, p. 508.

In the case of β Lyræ, Lockyer supposes that two swarms revolve round a principal mass, or "condensing nebulæ," of which the magnitude is 4·5.[1] One of these has a period of revolution of about 6 days, and the other of about 12 days. The former of these raises the light at periastron (by collisions) to magnitude 3·4.[1] The latter only raises the light to 3·9.[1] If we suppose the apastra of the two stars to occur simultaneously, there will be two minima, "*but the maxima will be constant.*"

Lockyer thinks "that practically there can be no permanently dark bodies in space; they *must* at one time or another be accompanied by comets, and they must therefore be variables."

In the concluding chapter of his work he sums up the general conclusions arrived at. He says (p. 532):—

"25. The relatively small number of bodies in Group VI. seems to suggest that in the part of space open to our inquiries, bodies of which the temperature is increasing are more numerous than those in which the temperature is being reduced.

"26. In recorded time there has been no such thing as 'a world on fire,' or the collision of masses of matter as large as the earth, to say nothing of masses as large as the Sun; but the indicated distribution of meteorites throughout space indicates that such collisions form an integral part of the economy of nature."

The latter passage reminds us of Dr. Croll's "Impact Theory" (see chapter on "Stellar Evolution").

In a paper read before the Royal Society in November 1888 by Professor G. H. Darwin, he examines mathematically the question whether the conception of fluid pressure, required by the nebular hypothesis, is applicable

[1] I have corrected the magnitudes given by Lockyer, which are incorrect.

to a swarm of meteorites. He finds that such a swarm may be compared to a gas, which is supposed to consist of an immense number of molecules separated by small but finite spaces. "According to the Kinetic theory of gases, fluid pressure is the average result of the impacts of molecules. If we imagine the molecules magnified until of the size of meteorites, their impacts will still, on a coarser scale, give a quasi-fluid pressure. He suggests then that the fluid pressure essential to the nebular hypothesis is in fact the resultant of countless impacts of meteorites."[1] This conclusion favours Lockyer's contention that space may be considered as "a meteoritic plenum."

In the Kinetic theory of gases the molecules are supposed to be perfectly, or at least highly, elastic, and in the collision of two meteoric stones Professor Darwin considers that, as a portion of each is volatilised, the result will be like that of an explosive, and consequently there will be nearly perfect elasticity between the colliding meteorites. He finds that the analogy with the theory of gases will hold good for the swarm from which the Solar System is supposed to have been evolved, a swarm extending beyond the orbit of Neptune. He finds that the swarm, when widely diffused, will be subject to gaseous viscosity, and will first rotate as a solid body, but when more contracted "the central portion will revolve more rapidly than the outside."[1]

Here closes, so to speak, the case for the plaintiff.

Let us now consider the facts and arguments which have been brought forward by the opponents of Lockyer's

[1] *Monthly Notices*, R.A.S., February 1889.

hypothesis, taking the various points in the order in which they are discussed in Lockyer's work on the subject.

First, with reference to the magnesium fluting near 500, observed in the spectra of meteorites, Professors Liveing and Dewar find that this fluting does not represent a lower temperature than the triplet *b*, as Lockyer maintains. They also find "that it is a fluting of an *oxide* of magnesium, and is scarcely seen in the presence of hydrogen,"[1] while undoubtedly hydrogen lines are seen in combination with the line near 500 in the nebular spectra.

With reference to Lockyer's assumption of the identity of origin of luminous meteors and falling stars with meteoric stones, Mr. Monck contends that we have no certain proof that meteorites come to us from external space. Sir Robert Ball and Tschermak consider meteorites to be "of terrestrial origin, having been shot from terrestrial volcanoes in past ages, when volcanic action was more powerful than at present."[2] Mr. Monck does not agree with this view, and points out that those connected with comets cannot be of terrestrial origin. He admits, however, that *some* meteorites may be of terrestrial origin, and suggests that Mr. Lockyer's experiments may have been made with some of these terrestrial meteorites.

With reference to the characteristic line of the auroral spectrum, which Lockyer identifies with the manganese fluting at 558, Dr. Huggins, in a paper read before the Royal Society in 1889, gives the results of some observations of the spectrum of the aurora made in the year 1874, and comes to the conclusion that the wave-length of the auroral

[1] *Journal of the British Astronomical Association*, No. 1, vol. i., p. 29. *Journal of the Liverpool Astronomical Society*, June 1888.

line is 5571 $\pm$ 0·5. After discussing the various measures of the line made by other observers, he says :—

"It is certain, therefore, from Angström's first observation in 1867 alone, that the aurora line lies well on the more refrangible side of wave-length 5580."

And again :—

"After consideration, I think that I ought to point out that Mr. Lockyer's recent statement that 'The characteristic line of the aurora is the remnant of the brightest manganese fluting at 558' is clearly inadmissible, considering the evidence we have of the position of this line."[1]

Another objection to Lockyer's meteoritic theory of the aurora was communicated to the Royal Society towards the close of the year 1890 by Professors Liveing and Dewar. These physicists describe some experiments which they made with a view to decide the question "whether solid particles of sufficient minuteness would act like gaseous molecules in an electric discharge, and become luminous with their characteristic special radiation." This they find not to be the case. Dust formed by particles derived from magnesium, iron, manganese, cadmium, fused calcium chloride, metallic sodium, and fragments of the Dhurmsala meteorite was employed in the experiments, the dust being generated from a pair of electrodes formed from the materials mentioned. The experiments showed that the electric current drove the dust granules from its path and cleared them off the electrodes. In no case could the lines characteristic of the materials composing the dust be

[1] *Proceedings of the Royal Society*, Vol. XLV., pp. 434,

detected in the spectrum. From these experiments the authors think that "if the spectrum of the aurora be due, not to the ordinary constituents of our atmosphere, but to adventitious matter from planetary space, we conclude that such matter must be in, or must be brought into, the gaseous state, or at least have its properties entirely altered from those it possesses at ordinary temperatures, before it becomes luminous in the electric discharge."[1]

With reference to the supposed connection between meteors, meteoric showers, and comets, the theory that comets originated *within* the Solar System was held by the famous Kant, and that they had their origin in external space by the equally famous Laplace. Professor H. A. Newton, who has carefully investigated the subject, although he favours the hypothesis of Laplace, arrived by calculation at results which, according to Mr. Monck, seem equally favourable to both hypotheses. Mr. Monck inclines to the opinion that some comets, at least, have originated "within the limits of the Solar System," and to this class he is disposed to assign "the four comets which have been connected with meteor showers."[2]

Coming now to one of the crucial tests of the meteoritic hypothesis, namely, the supposed coincidence of the "chief nebular line" with the "remnant of the magnesium fluting" near wave-length 500, Dr. Huggins made a re-determination of the exact position of the principal line in the Orion nebula in February 1890, and after a series of careful measurements he arrived at the result that the wave-length of the nebular line is about 5004·75, while that of "the

[1] *The Observatory*, December 1890.

[2] *Journal of the Liverpool Astronomical Society*, June 1888.

termination" of the magnesium band is 5006·5. Dr. Huggins also says "that a marked feature of this line (the nebular line) is its sharply defined character on the more refrangible side; we were unable, under any of the conditions of observing, to detect even a suspicion of any softening of the more refrangible edge of the line, much less the faintest indication of a 'flare,' and certainly not the distinctive peculiarity of a 'fluting.'[1] From observations of the hydrogen line in the same spectrum, Dr. Huggins finds that "the nebula has very little, if any, sensible motion in the line of sight."[2] The nebular line cannot therefore be displaced by any motion of the nebula.[2] These observations were confirmed by Mrs. Huggins and by Professor Liveing, using the same telescope and spectroscope. Dr. Huggins therefore concludes,

"(1) That the principal line is not coincident with, but falls within, the termination of the magnesium-flame band.

"(2) That in the nebula of Orion this line presents no appearance of being a 'fluting.'"

He finds the same result in the spectrum of the nebula Σ 5 (G. C. 4234).

Dr. Huggins' result as to the sharp character of the line was confirmed by Professor Young and by Mr. Keeler at the Lick Observatory. Mr. Keeler observed "successively

[1] *Proceedings of the Royal Society*, Vol. XLVIII.

[2] It should be remembered, however, that as the Sun's motion in space is *away* from the Orion nebula, the spectrum should show—if the nebula be at rest—a motion of recession. The fact therefore of the hydrogen line showing no displacement would imply that the nebula has a motion in space in the same general direction as the Sun's motion, and with nearly the same velocity. More recently Mr. Keeler finds a motion of recession in the Orion nebula at the rate of 10·7 miles a second.

with one prism, a powerful compound prism, and then with a Rowland grating, 14,000 + lines to the inch." He says: "One thing that struck me particularly, and that there could be no doubt of, was the perfect sharpness and fineness of the nebular lines under the very considerable dispersion used. There is not the least doubt in my mind that they are all of gaseous origin—not remnants of flutings."[1]

Subsequently Dr. Huggins' results with the nebula Σ 5 were also confirmed by Mr. Keeler. He says, in a letter to Dr. Huggins: "On comparing the brightest line with the magnesium fluting, both directly and by aid of the micrometer wire, the line was seen to be well within the limits of the fluting, and separated by a small but unmistakable interval from the bright lower edge. . . . The edge of the fluting *could not* be brought into coincidence with the nebular line."

Mr. Keeler subsequently examined the spectra of a number of planetary nebulæ, and arrived at a similar result with respect to the position and character of the principal line, the mean wave-length deduced from ten nebulæ being 5005·68, that of the magnesium fluting being 5006·36. The nebular line, however, showed a displacement, apparently due to the motion of the nebulæ in the line of sight.

With reference to this shift in the position of the line, Mr. Maunder says: "The amount of the displacement is not so great as to make it altogether inconceivable that it is due to the relative motion of the nebulæ and the Solar System. For all the ten nebulæ are observed in that hemisphere towards which the Sun is travelling, and seven

[1] *Proceedings of the Royal Society*, Vol. XLVIII.

of them are within 45° of the apex of the 'Sun's Way,' so that a correction must be applied which would tend to bring the nebular line nearer to the fluting ; how much nearer we cannot, in our ignorance of the speed of the Sun's motion in space, at present say, but the rate of 36 miles per second would suffice to make the accord a perfect one" ;[1] and in a paper in the first number of the *Journal of the British Astronomical Association*, Mr. Maunder adds : "Further, some allowance must be made for the difficulty of comparing a line with a fluting ; we ought certainly not to measure from the centre of the nebular line to the extreme edge of the fluting. This will supply a small but further correction in the same direction. Keeler's observations so far, therefore, point distinctly to a close approximation of the nebular line to the position occupied by the maximum of the fluting, but whether there is or is not an exact coincidence we cannot yet tell. . . . The conclusion is, then, that we do not know the position of the nebular line with sufficient accuracy to say positively that it does or does not accord with the magnesium fluting."[2]

Here the matter rests at present (January 1892). One point is clear, however, that the dispersion used by Professor Lockyer was insufficient to decide the question, and further researches on the subject will be looked forward to with great interest.

There seems to be another weak point in Professor Lockyer's theory, and that is that it affords no explanation

[1] *The Observatory*, November 1890.

[2] Subsequent measures by Mr. Keeler give the *true* position of the "chief nebular line," when corrected for the earth's orbital motion and the Sun's motion, at 5005·93, thus showing that it does *not* coincide with the magnesium fluting (*Journal B.A.A.*, Vol. I., No. 5, pp. 281, 282).

of how the planets and satellites of the Solar System were evolved. This has been pointed out by Mr. Monck. He says : " Will any advocate of the meteoritic theory give us an explanation of why all the planets and asteroids and the great majority of the satellites revolve in the same direction, why the orbits of the larger bodies of the system deviate so little from the circle, and why they are so nearly in the same plane? Till this is done I think the nebular hypothesis has in this case the advantage."[1] A violent "grazing collision" between two dense meteoric swarms might, however, conceivably be supposed to produce a rotation in the swarm which would give rise to the observed planetary motions.

"In the *Comptes Rendus* of November 28th, 1887, M. Stanislas Meunier objects to Mr. Lockyer's hypothesis that meteorites are made up of metals whose melting points are so different that the agglomeration cannot be supposed to have occurred at a high temperature."[2]

Another objection raised by Mr. Monck is that it seems difficult to understand how the requisite number of collisions in a meteoric swarm could be produced and kept up, and "that meteor-clouds dense enough to produce the requisite amount of light by their collisions would also be dense enough to intercept a great part of it again on its way to the earth."[3]

On the whole, therefore, we seem bound to conclude that the "weight of evidence" is against the truth of the "Meteoritic Hypothesis."

[1] *Journal of the Liverpool Astronomical Society*, November 1890, p. 36.
[2] *The Observatory*, January 1888.
[3] *Journal of the Liverpool Astronomical Society*, June 1888, pp. 289, 290.

CHAPTER IX.

THE MILKY WAY AND STAR DISTRIBUTION.

"Seen in the galaxy, that milky way,
Which nightly, as a circling zone, thou seest
Powdered with stars."

MILTON.

THE nebulous band or zone of light known as the Milky Way, or Galaxy, is familiar to every one, and on a clear moonless night forms a conspicuous feature of the nocturnal heavens. It has attracted the attention of astronomers and philosophers from the earliest ages of antiquity, and various theories have been advanced to account for its appearance. One of the ancient writers—Oenopides—considered it to be the original course of the Sun. Plutarch saw in it the marks of Phæton's accident.[1] Anaxogoras thought it was the shadow of the earth, and Aristotle that it was due to atmospheric vapours!

Other equally absurd theories were entertained by the ancients, and Ovid says, in the first book of the Metamorphoses: "When the sky is clear a path of very radiant

[1] Phæton, son of Phœbus and Clymene, in ancient mythology, requested permission from his father to drive the chariot of the Sun, but after a few hours' driving, overcome by the heat, he dropped the reins. To prevent a general conflagration Jupiter struck him with lightning, and he dropped into the river Eridanus, now one of the constellations.

white colour may be seen in the empyrean. It is called the *Milky Way*, and along it the immortals repair to the august dwelling-place of the Lord of Thunder," a fable which is also referred to by Plato. The true theory, namely, that its light originates from myriads of small stars, was, however, advanced by Democritus, Manilius, and Pythagoras, and the invention of the telescope fully confirmed the correctness of this hypothesis.

Before proceeding to inquire into the construction of the Milky Way, and the modern theories which have been advanced respecting its relation in space to the Sun and Solar System, it will be interesting to make an examination of its general appearance and structure as depicted by different observers.

The representations of the Milky Way given in Proctor's and other popular atlases merely afford a general idea of its appearance, and show no details of the brightness and faintness of its various parts—features which are very obvious when carefully observed. A mere passing glance might lead a casual observer to suppose that the Galaxy stretched as a band of nearly uniform brightness across the heavens. But good eyesight, careful attention, and a clear sky will soon disclose numerous details previously unsuspected, streams and rays of different brightness intersected by rifts of darkness, and interspersed with spots and channels of comparatively starless spaces.

Heis, in his excellent *Atlas Cœlestis Novus*, gives an elaborate delineation of the Galaxy, as seen in northern latitudes. According to his drawing the general course of the Milky Way nearly coincides with a great circle of the celestial sphere, having its mean centre line inclined to

the Equator at an angle of about 65°, and intersecting that circle in about R. A. 7h. and 19h. The intersection at 19h. is that of the mean centre line of the *main branch*, which passes over *a*, δ, and λ Aquilæ, and λ and δ Sagittarii. If, however, we assume the centre line to pass from γ Cygni between the divided branches in Aquila and Ophiuchus, the intersection at this point with the Equator will be at about R. A. 18h. 40m.

According to Sir John Herschel the position of the North Pole of the Milky Way is R. A. 12h. 47m., and North Declination 27°. Heis gives it R. A. 12h. 41·2m., N. 27° (1880); Houzeau R. A. 12h. 49m., N. 27½; and Gould R. A. 12h. 41m. 20s., N. 27° 21′ (1875)—results in fairly close agreement. The South Pole is in about R. A. 0h. 47m., and Declination S. 27°. The near coincidence of the course of the Milky Way with a great circle of the star sphere implies of course that the Sun and Solar System are situated in or close to the general plane of the Galaxy.

Heis divides the varying brightness of the different parts of the Milky Way into five magnitudes, the first magnitude corresponding to the luminous parts of the Galaxy between γ and η Cygni; near the variable star R Scuti ("Sobieski's Shield"); and the bright spots near the bow of Sagittarius; and the fourth and fifth magnitudes to the very faint nebulous light which he shows filling in the vacuities or "coal sacks" in Cygnus and Cepheus and bordering the Milky Way on both sides throughout nearly the whole of its course.

This method of division into magnitudes is of course, to a great extent, an arbitrary one, and the lines of demarcation between Heis' assumed magnitudes are not so sharply

defined in the sky as shown in his maps. There is also reason to think that Heis did not pay so much attention to the Milky Way as he did to his stellar magnitudes.[1] Still his drawing serves to give a fair representation of the general effect visible to a keen-sighted and careful observer, as Heis undoubtedly was.

Following Heis' picture of the Galaxy in order of Right Ascension, commencing at Cassiopeia's Chair, we find that the well-known square formed by β, α, γ, and κ Cassiopeiæ is nearly filled in with nebulous light of about Heis' second order of brilliancy. This bright spot extends north of δ Cassiopeiæ up to ϵ, where it merges into a long elongated spot of about the third magnitude, extending from β Cephei to the borders of Camelopardus, and reaching with fainter light nearly to the Pole Star, where it joins an oval-shaped patch, of about fourth magnitude, covering the hind legs of the figure.

From δ and ϵ Cassiopeiæ the brightness is of about the third and fourth magnitude, its width being reduced to a very narrow neck north of ι Persei. This narrow isthmus of light lies at the south-western extremity of a large vacuity or "coal sack," which is bounded on the north by the oval-shaped spot above referred to, and its southern limit is roughly defined by the well-known curved stream of stars formed by γ, α, ψ, δ, μ, and λ Persei. From near this stream a branch is thrown off from the Galaxy towards the south, enclosing near its southern extremity ζ and o Persei, the stars ϵ and ξ Persei lying on its eastern

[1] An elaborate drawing of the Milky Way has recently been made by Dr. Otto Boeddicker (of Lord Rosse's Observatory). This will be described further on.

boundary. From α and ϵ Persei to α, ϵ, ζ, and η Aurigæ the Milky Way is shown rather narrow and of nearly uniform brightness.

South of this the stream widens out considerably, reaching a maximum width between δ Geminorum and α Orionis. Here there are several spots slightly brighter than the rest, one especially of roughly circular form (about second order of brightness) enclosed by ϵ, ζ, and 48 Geminorum,[1] one just north of η and μ Geminorum, and a vacuity (or spot with faint light) extending from η Geminorum to the variable star S (15) Monocerotis.

From the latter star the Milky Way proceeds southerly with a somewhat increased and nearly uniform brightness across Monoceros and into the constellation Argo, where its brilliancy still further increases to 35° South Declination, at which point the stream passes below the boundary of Heis' maps. South of ξ and π Argûs, Heis shows a long narrow vacuity or "coal sack," and the northern portion of another a little to the east (both of these are shown by Proctor).

The eastern border of the former "coal sack" is the brightest portion of the Galaxy in this vicinity as drawn by Heis. This forms a good illustration of a remarkable feature of the Milky Way, viz., that bright streaks and dark vacuities are in several cases found close together, a feature which will have to be explained by any satisfactory theory of this wonderful zone.

Let us now return to the point we started from in Cassiopeia, and trace the course of the Milky Way, as shown by Heis, in the opposite direction. From β Cassio-

[1] Here Proctor shows no Milky Way light.

peiæ a narrow band of bright nebulosity extends towards the head of Cepheus, and spreading out covers a large area, including a vacuity in which δ, ϵ, ζ, and λ Cephei are situated. This "coal sack" is filled in with very faint nebulous light (about fifth order of brightness).

Between this and α Cygni is another oval-shaped vacuity, the centre of which seems quite free from nebulosity [from which a narrow dark rift passes across the Milky Way between ξ and ρ Cygni. This "rift," although very conspicuous to the eye, is, curious to say, entirely omitted by Heis, who shows in its place a very bright patch extending from ρ Cygni to o^1 and o^2]. From α Cephei a long vacuity stretches as far as ω and ϵ Cassiopeiæ. From α Cygni to Sagitta the Galaxy is very luminous, all the dark spaces shown in most star atlases being filled in, according to Heis, with faint nebulosity.

The brightest part of this region is an elongated spot extending from γ to β Cygni, the brightest part of all lying between γ and η Cygni. In this spot Heis shows three gradations of brightness, bounded by a fainter region towards Lyra, and by a long vacuity (or very faint region) on the opposite side (see Plate II.). A fairly bright region, however, extends from ν and σ Cygni to μ Aquilæ, the brightest part including the brighter stars of Sagitta and γ, π, χ, and ψ Aquilæ. From this region a fainter extension includes the brighter stars of the Dolphin's rhomb. The actual bifurcation of the two streams of the Milky Way (only partially separated in Cygnus) takes place between γ and ζ Aquilæ.

Following the western or "broken branch," which is bright in the vicinity of ϵ and ζ Aquilæ, a patch of fainter

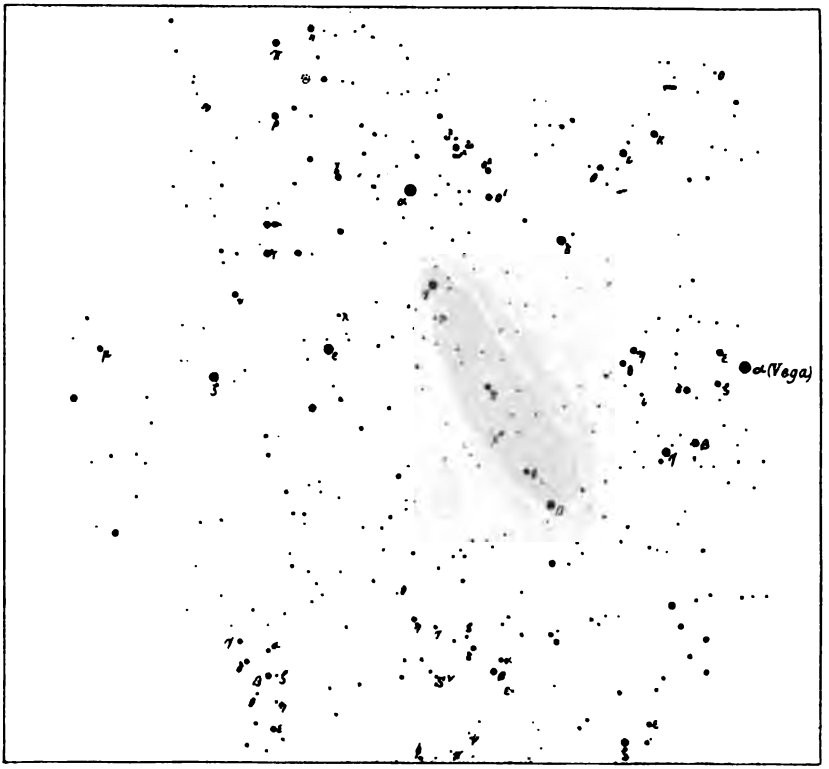

PLATE II.

The Milky Way in Cygnus,

As drawn by Heis.

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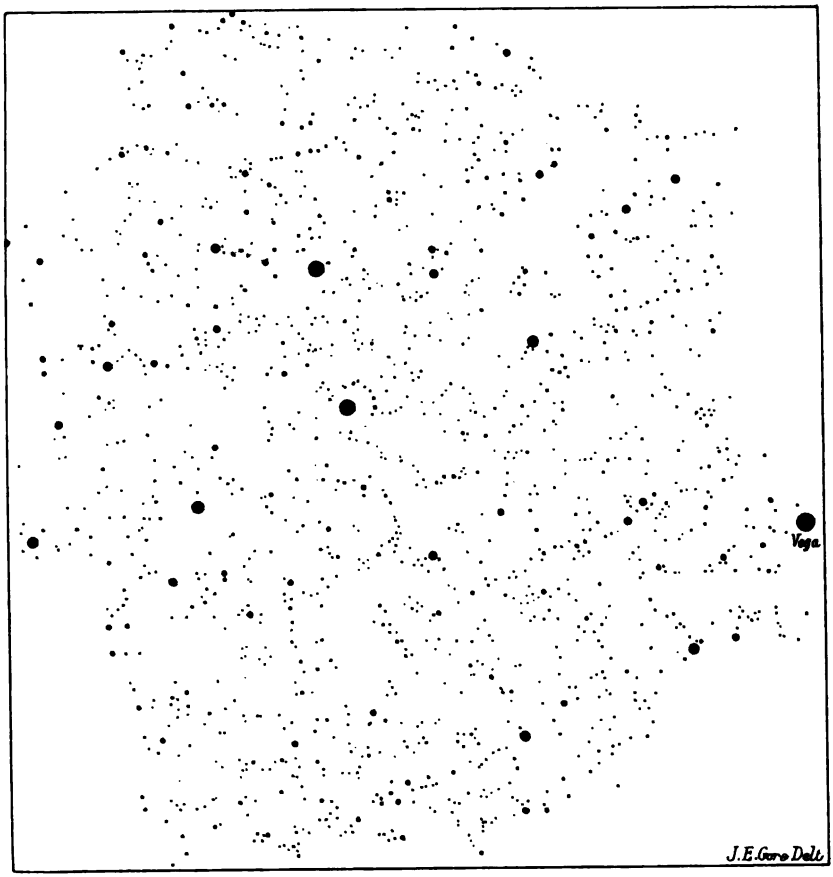

PLATE II[a]

The Milky Way in Cygnus,

After Boeddicker

Stars to 8th magnitude from Harding.

light occurs, then another brighter portion (but of varying brightness) extends to and includes the small group of stars formed by 67, 68, 70, 73, and 74 Ophiuchi, and seems to end in a point, the whole branch bearing a striking resemblance to a human leg and boot (see Plate III.).

It is, however, bounded on the west by very faint nebulosity, which extends from Lyra to about 41 Ophiuchi, and includes β, γ, σ, 71, and 72 Ophiuchi. Just south of 68 Ophiuchi the branch is completely broken across for a width of about 6°, but again recommences in faint light near τ Ophiuchi, with a much brighter circular spot between μ and ν Ophiuchi [not shown in Proctor's Atlas]. This faint light extends southerly to the stars 40 (ξ) and 58 Ophiuchi, another small bright spot occurring at the latter star. From η Ophiuchi, however, a very bright branch extends in a southerly direction past θ Ophiuchi, and then, becoming somewhat fainter, it passes below the limit of Heis' map. A little north of λ Scorpii Heis shows a narrow "bridge" connecting the two streams of the Milky Way, and stretching towards θ Ophiuchi.

Returning now to α Aquilæ (Altair), the eastern or main branch extends in a narrow but luminous stream through Aquila Scutum and the bow of Sagittarius. This branch includes several spots of superior brilliancy, of which the most remarkable are: a curved one near δ Aquilæ, of which the convexity seems to follow the stars δ, 35, ν, and d Aquilæ, with the concavity turned towards θ Aquilæ; one covering "Sobieski's Shield" (Scutum), its northern edge being bounded by λ and 12 Aquilæ, and a fifth-magnitude star north of the variable R Scuti; several small

circular spots near μ Sagittarii;[1] and a long curved spot between λ and μ.

There is a fainter region [not shown by Proctor] to the east, which includes the stars ν, π, o, ξ, υ, σ, ϕ, τ, ζ, and δ Sagittarii. The main branch here passes over γ Sagittarii and below the limit of Heis' map. These bright spots in Sagittarius are shown by Heis of about the same brightness as the spot near γ Cygni; but, as far as my own experience goes, there is no portion of the Milky Way in the Northern Hemisphere at all comparable in brilliancy with the clouds of light in Sagittarius and Scorpio as seen in the Punjab sky.

With reference to this point Colonel Markwick says[2]: "Certainly the Milky Way about the neighbourhood of Lupus, Ara, and Norma is a wonderful spectacle, full of a mysterious weirdness, with its delicate cloud-like wisps of light and dark passages twining in and out among the star mist. To my mind there is no part of the Northern Milky Way to compare to this. The dry clear air of the uplands of South Africa, away from the coast, is very conducive to brilliant displays of the Galaxy. More particularly on August 3rd, 1885, at Taungs, in Bechuanaland, the portion between Sagittarius and Scorpio appeared all broken up into cloudy flocculent masses, reminding one of those light clouds seen when mist or fog is clearing away under the influence of the Sun.

"I have often thought of sketching it, and made one or

[1] These circular spots, as drawn by Heis, seem to resemble the Magellanic Clouds, and the argument for a probably globular shape seems to apply here also.

[2] *English Mechanic*, May 28th, 1886, p. 279.

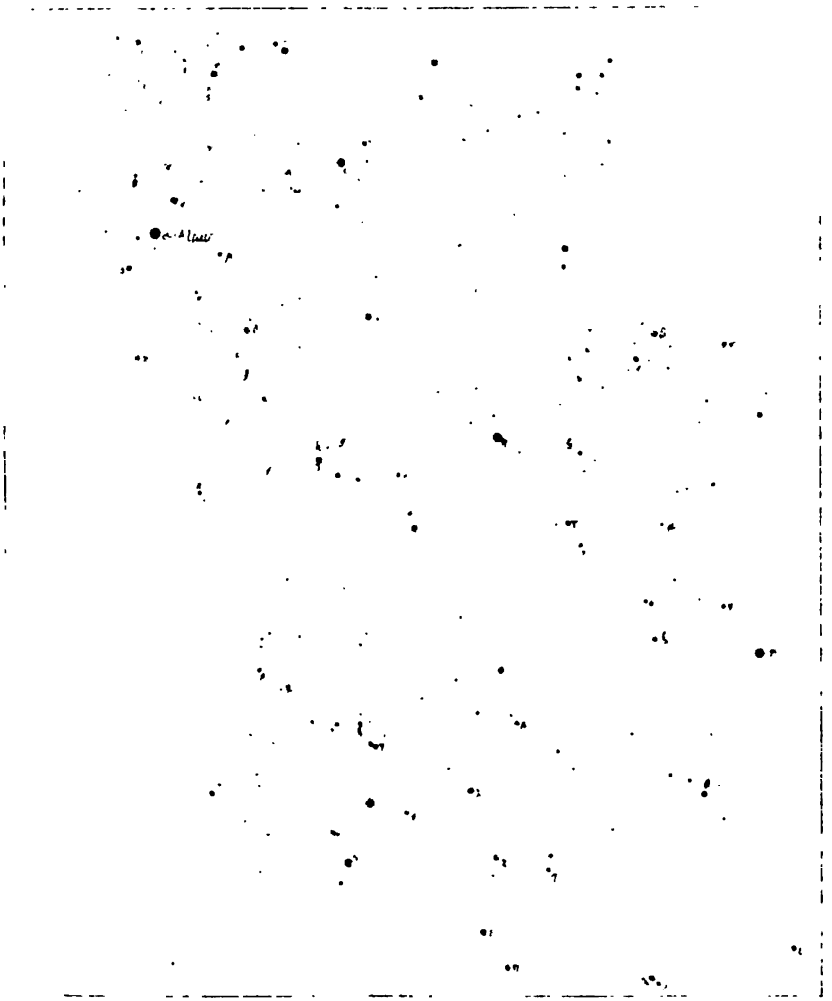

PLATE III.

Bifurcation of the Milky Way in Aquila & Serpens,

As drawn by Ilois.

[illegible] Sagittarii;[1] and a long curved spot

[illegible] [not shown by Proctor] [illegible] the [illegible] stars ν, π, o, ξ, υ, σ, ϕ, τ, ζ, and δ [illegible] branch here passes over γ Sagittarii [illegible] Heis' map. These bright spots in [illegible] Heis of about the same brightness [illegible]; but, as far as my own experience [illegible] of the Milky Way in the Northern [illegible] comparable in brilliancy with the cloud [illegible] and Scorpio as seen in the Pu[illegible]

[illegible] point Colonel Markwick sa[illegible] Way about the neighbourhoo[illegible] Lupus, Ara, and Norma is a wonderful spectacle, full of [illegible] mysterious w[illegible], with its delicate cloud-like wisp[illegible] of light and dark passages twining in and out among the star mist. To my mind there is no part of the Northe[illegible] Milky Way to compare to this. The dry clear air of the [illegible] of South Africa, away from the coast, is very con[illegible] to brilliant displays of the Galaxy. More particu[illegible] on August 3rd, 1885, at Taungs, in Bechuanaland, the [illegible] between Sagittarius and Scorpio appeared all broken into cloudy flocculent masses, reminding one of those [illegible]ht clouds seen when mist or fog is clearing away under the influence of the Sun.

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[1] These circular spots, as drawn by Heis, [illegible] Magellan Clouds, and the argument for a probably [illegible] apply here also.

[2] *English Mechanic*, May 28th, 1886, p. 279

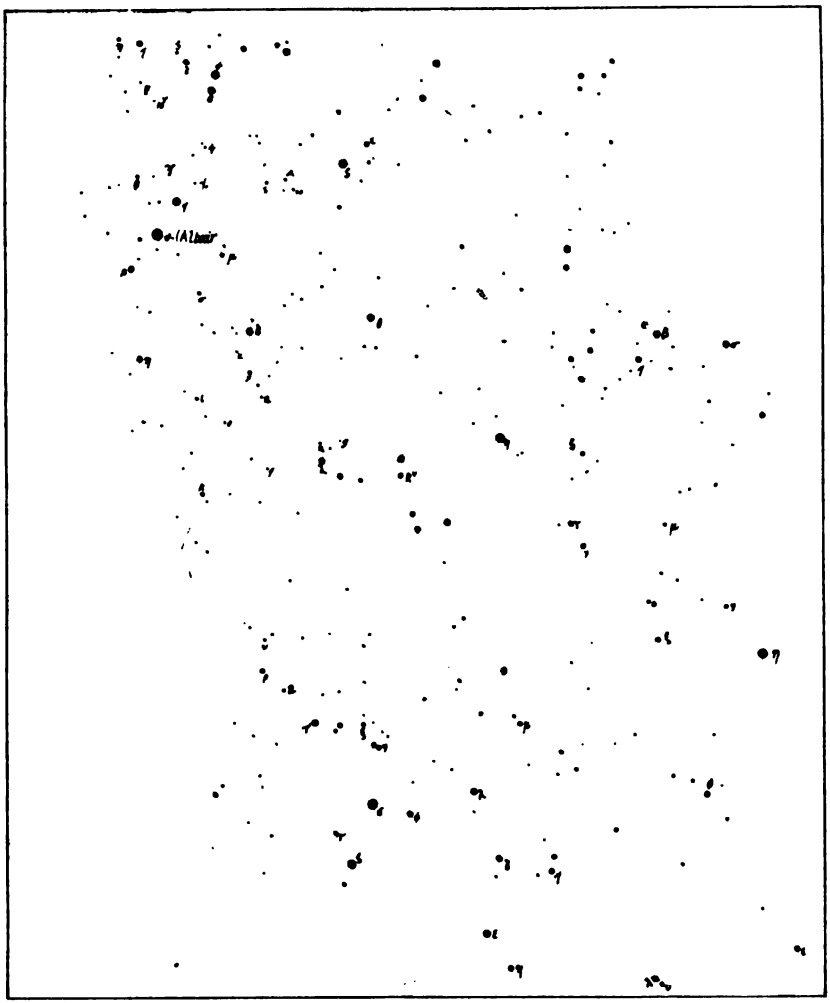

PLATE III.

The Bifurcation of the Milky Way in Aquila & Serpens,

As drawn by Heis.

two attempts, but the very light necessary for the use of the pencil seems to render the eye not sensitive to the most delicate features, and one could not but imagine what an extremely difficult task it would be to render it with strict fidelity to nature, and to preserve the same scale of brightness throughout" ; and again[1] he says : "Whether it is owing to the clearer air or not, the Milky Way is far more impressive to me in the Southern than in the Northern Hemisphere."

The bright spot in "Sobieski's Shield," mentioned above, is, however, very luminous in a dark sky in this country towards the end of July.

To complete the description of the Milky Way, as shown by Heis, I will now follow its course, below the limit ot Heis' maps, as depicted by Sir John Herschel in his *Cape Observations*. Starting from the spot in Argo where Heis leaves it, we find that the two vacuities mentioned above, as shown by Heis, are also given by Sir J. Herschel, and of a very similar outline and character, especially in the brilliancy of the borders of the northern vacuity. Immediately south of these dark spaces the Milky Way widens out and apparently terminates in four fan-like projections, forming the well-known "gap in Argo."

Here its continuity is completely broken across—at least, apparently—for a width of several degrees. The stream then recommences in three somewhat similar projections, and, suddenly diminishing in width, passes over the famous variable star η Argûs, at which point it throws off a curved branch towards the "gap" above referred to. This offshoot passes between η and θ Carinæ, the latter star being in-

[1] *English Mechanic*, Vol. XLIX., p. 259.

volved in faint nebulous light. It then further contracts in width before reaching the Southern Cross, the southern boundary of this neck or "isthmus" being sharply defined and of a semicircular shape, with the concavity turned towards the south. It then suddenly expands into a broad and luminous stream, which includes α and β Crucis and β Centauri and the well-known dark hole or vacuity known to navigators as "The Coal Sack."

This very remarkable spot—considered by some observers to be the most extraordinary feature of the southern sky—is "a pear-shaped oval" about 8° in length and 5° in width, with its longer axis "nearly parallel to a line joining α and β Crucis," and completely surrounded by the Galactic light which in this vicinity is very luminous. Its apparent blackness to the naked eye seems to be chiefly due to the effect of contrast with the rich surrounding region, as Sir John Herschel found it to contain numerous telescopic stars and no "blank fields" resembling those which he observed in other portions of the southern sky. He found, however, in "sweeping" across it with his 20-feet reflector, that "the transition from rich Milky Way to almost complete darkness is here very sudden." Its blackness, therefore, is simply due to a paucity of stars, and it forms another example of rich and poor regions in close proximity.

The bright stream of Milky Way light continues its course over β, but just before reaching α Centauri it divides into *two* streams, one spreading out over Scorpio, and the other, or main stream (the *following* one), continuing its course through Sagittarius and Scutum to Aquila.

This is the so-called southern bifurcation of the Milky

Way. An examination of Herschel's beautiful drawing of this region leads me, however, to the conclusion that we may simply consider the so-called second branch as merely an *expansion* of the Milky Way in this region, this expansion including a number of larger vacuities or "coal sacks."

The general aspect of the Milky Way in this vicinity very much resembles—at least, on Herschel's drawing—the northern expansion extending from Cygnus to Auriga,[1] which Heis shows as really continuous, although its uniformity is *apparently* interrupted by vacuities, which have been already described. On this view of the matter we may perhaps consider the branch extending from ϵ and ζ Aquilæ to γ Ophiuchi as being merely an offshoot from the general stream, similar to the branches which extend to ξ and o Persei, and to ι and κ Andromedæ.

The Milky Way patches and vacuities, as depicted by Herschel in Ara and Scorpio, are so complicated that no verbal description would give an adequate idea of their appearance, and his delineation of the portion extending from a Scorpii to o Ophiuchi differs considerably from Heis' drawing. Herschel, however, shows the narrow "bridge" stretching from the so-called main stream towards θ Ophiuchi, shown by Heis.

Herschel's description of the complicated structure of the Milky Way in this region as seen with his 18¼-inch reflector is very interesting. With reference to the bright spot round γ Sagittarii he says: "It forms one of the most intense and striking developments in the form of an oval

[1] I am here referring to the *naked eye* configurations of the two regions, not to their telescopic constitution.

luminous mass, about 6° in length and 4° in breadth, and in which, intermixed with gauges of 200 stars in the field, occur portions of such richness that it was found impossible to count the gauges, and *that* in a zone 3° in breadth, over an interval of R. A. from 17h. 45m. to 18h. 30m. A very moderate calculation indeed would make the number of stars in this mass upwards of 100,000."

With reference to what he calls the "preceding stream, diverging from γ Normæ," he found the richest portion between the 118th and 119th parallel (of North Polar Distance) (Heis' bright branch from η Ophiuchi). Here the telescope showed 120 stars per field of 15 minutes, "from which point northwards they decrease to 42, 60, 40, 37, 48, etc., and finally again attain 60 and 66." Between ϵ and λ Scorpii "this branch first presents the phenomena of nebulosity irresolvable in the 20-feet reflector, 16h. 48m."; and on entering the region between the streams he says that in the same sweep at R. A. 17h. 13m. "the northern end of the zone, though pretty rich in *stars*,[1] is yet quite free from brightness of ground. It is as black as a coal."

The significance of this latter remark will be noticed in subsequent chapters when we come to speak of the supposed extinction of light and the limited number of the visible stars.

With reference to the irresolvable nebulosity noticed by Herschel in the above sweeps and in some other places, a little consideration will show that this appearance of nebulosity was probably due simply to deficiency of light in his metallic mirror. Assuming, as Herschel himself estimates, that for refractors and metallic mirrors giving equal light the ratio of the apertures is as 5 to 7, Herschel's

[1] The italics are Herschel's.

mirror of 18¼ inches aperture would be about equivalent to a refractor of 13 inches, in which I find—by Pogson's formula[1]—the faintest stars visible would be about magnitude 14¾. The Milky Way contains, we now know, thousands of stars fainter than the 15th magnitude, and a cloud of these fainter stars would of course appear nebulous in Herschel's instrument.

Whether modern telescopes, aided by photography, will show any nebulous light in these regions remains to be seen; but, judging from the stellar photographs taken at the Paris Observatory, it seems highly probable that Herschel's nebulous "patches and banks" will be clearly resolved into minute stars.[2] In a sweep at R. A. 17h. 50m., and about 35° S. Declination, Herschel says: "The Milky Way is like sand, not strewed evenly as with a sieve, but as if flung down by handfuls (and both hands at once), leaving dark intervals, and all consisting of stars 14 . . . 16 . . . 20m. down to nebulosity, in a most astonishing manner,"—a good example of the clustering tendency, which will be considered in a subsequent chapter.

Again, at R. A. 17h. 53m., he says: "After an interval of comparative poverty, the same phenomenon, and even more remarkable. I cannot say it is *nebulous*. It is all resolved, but the stars are inconceivably numerous and minute. There must be millions on millions, and all are most unequally massed together, yet they nowhere run to nuclei or *clusters much brighter in the middle.*"[3]

[1] $l = 9{\cdot}2 + 5 \log$ aperture.

[2] Photographs of the Milky Way near α Cygni by Dr. Max Wolf show, however, nebulous light mixed up with the small stars of the Galaxy.

[3] The italics are Herschel's.

From what has been said above with reference to the light-grasping power of Herschel's telescope, it will be seen that he largely under-estimated the magnitude of the fainter stars visible in his instrument. It is very doubtful whether any telescope yet constructed would show—at least, to the eye[1]—a star of the 20th magnitude, if such faint stars exist. The faintest star visible in the great Lick telescope (36 inches aperture) is, by Pogson's formula, only of the 17th magnitude (see Appendix, Note B). Sir John Herschel estimated that the total number of stars visible in his telescope would be about 5½ millions.[2] This estimate was, however, probably too small.

In some places Herschel found the border of the Milky Way sharply defined from the general background of the sky. At one point, for instance, he observed "a great nebulous or almost nebulous protuberance or promontory which projects into the field of view as the Cape of Good Hope on a map does into the Southern Ocean"; and at another place (R. A. 17h. 48m., S. 21° 2′) he says, "The apparent top of the field (the real bottom) is full of faint nebulous light without stars: the rest of the zone is blank."

We next come to Houzeau's delineation[3] of the Milky Way, which, as the independent work of *one* observer for *both* hemispheres, has a certain value, although his drawing is somewhat diagrammatic, and evidently deficient in detail. The method of representation adopted by Houzeau is to trace the lines of equal brightness (or "isophotes," as he

[1] Faint stars have, however, been *photographed* which are quite invisible to the eye in the telescope with which they were photographed.

[2] *Cape Observations*, p. 381.

[3] *Annales de l'Observatoire Royal de Bruxelles* (Nouvelle Série), "Astronomie," Tome I., 1878.

terms them) of the various portions of the Milky Way. These somewhat resemble, he says, the "contour" lines or terrestrial maps, and are filled in with a blue tint, the washes of colour being placed one over the other, so that "plus il y a de courbes, plus l'espace renfermé dans la dernière est brillant."

As in Heis' drawing, Houzeau shows five gradations of brightness, and these he determined by comparing the brilliancy of different portions of the Milky Way with neighbouring stars of magnitudes 6-7, 6, 5-6, 5, and 4-5. In making this comparison he was guided by the appearance or disappearance of the luminous patches of Milky Way light in the twilight or moonlight simultaneously with the stars of comparison.

It seems doubtful, however, that this method is susceptible of any great accuracy, the comparison of a bright point, like a star, with a nebulosity extending over a considerable area being evidently a matter of much difficulty and considerable uncertainty. The visibility of the star and the adjoining nebulosity might not, in all cases, be equally affected by varying atmospheric conditions, and the gradations of light in the different portions of the Galaxy are so gradual, numerous, and complicated that many of the smaller details would unavoidably be lost in such a rapid survey of the heavens as that undertaken by Houzeau, who estimated the magnitude of all the stars visible to the naked eye (in addition to his drawing of the Milky Way) in the very short period of thirteen months (January 1875 to February 1876).

Houzeau seems to have been conscious of the uncertainty of his method, for he says: "Cependant il ne serait pas

exact d'en conclure que ces plaques brillants donnent autant de lumière qu'une nappe continue d'étoiles du 5m. ordre. Il est incontestable que leur étendue aide à les apercevoir, et que leur visibilité ne repose pas uniquement sur leur éclat spécifique." The drawing being, however, the work of a single observer and so accomplished an astronomer as the late M. Houzeau, and moreover executed from observations made in a favourably situated station like Jamaica, possesses a value to which it might not otherwise be entitled.

The extension of the Milky Way Zone, as drawn by Houzeau, is considerably less than that shown by Heis, much of the faint bounding nebulosity drawn by the latter observer[1] being wanting in Houzeau's delineation. According to a computation made by Herr J. Plassmann, the area covered by Milky Way light in Houzeau's drawing is about one-tenth of the whole star sphere, a considerably smaller area than the extension shown by Gould and Heis.

Houzeau shows the *nubecula major*, or greater Magellanic Cloud, with three gradations of brightness, the brightest spot, which includes β Mensæ, being of about the second order of brilliancy, or that corresponding to a star of the fifth magnitude. The smaller Magellanic Cloud —the *nubecula minor*—he shows with two gradations, the brighter tint corresponding to a star of about magnitude 5-6. He says that the *nubecula major* is mentioned in the tenth century under the name of "bœuf" (baker) by Al-Sufi, and adds: "Il etait visible, dit cet astronome, du sud de l'Arabie et de la mer Rouge. Ce furent les Indiens de l'Amérique qui attirèrent sur ces taches lumineuses

[1] Dr. Boeddicker doubts the existence of this faint nebulous light.

l'attention de Magellan. Les puelches de la Patagonie les croient composées des plumes les plus légères des autruches tuées à la chasses par leurs ancêtres."

To determine the position of the Northern Pole of the Galaxy Houzeau takes 33 points of maximum brightness (see Appendix, Note C) of Milky Way light. From the positions of these points he forms 33 equations of condition, attributing to each a weight proportional to its relative brightness. Solving these equations by the method of least squares, he finds for the position of the Northern Pole of the Milky Way for the Equinox of 1880·0

R. A. 12h. 49·1m., Decl. + 27° 30′,

a result in fairly close agreement with the positions found by Sir John Herschel, Heis, and Gould, but differing by 4° from the declination determined by the elder Struve.[1] Comparing this position of the pole with the observations, Houzeau finds a mean difference of only 20 minutes of arc, and says: "La moyenne—20′ de ces erreurs est la quantité dont la Voie Lactée est située du côté du sud. Or cette valeur est si faible qu'on peut évidemment regarder son cercle médian comme un grand cercle de la sphère."

For the following description of the Southern Milky Way, as delineated in Dr. Gould's *Uranometria Argentina*," I am indebted to the kindness of Colonel Markwick, F.R.A.S.: "The boundaries of the Galactic light,[2] as drawn by the Cordoba observers, are as follows: Commencing with θ Aquilæ, the extreme southern limit of faint nebulosity

[1] Struve's position reduced to 1880·0 is R. A. 12h. 40m., + 31° 30′.

[2] These boundaries may be useful to observers who would like to sketch in the limits of the Southern Milky Way on the maps in their possession.

ust envelops ρ Sagittarii, passes τ and ζ Sagittarii, thence to α Telescopii, touches η Pavonis, envelops α Triangulum Australis, thence to α Apodis, and touches β Chamæleontis. In this neighbourhood occurs the closest approach to the South Pole, from which it is distant about 11°. Thence by G Carinæ to A Carinæ, β Columbæ, β, λ Leporis, β Orionis, and β Eridani, near which star it crosses the Equator.

"The northern boundary starts from the Equator near η Serpentis, passes thence just over ν Ophiuchi, curves round by ν, β, δ Scorpii, over υ Libræ, between η and ζ Centauri, just envelops ι Velorum, touches L 4059 and 26 Hydræ, cutting the Equator in about 8h. 50m. of R. A.

"The most remarkable features of the Southern Milky Way, as drawn by Gould, are as follows: Commencing at the Equator in about 19h. R. A., a very brilliant patch occurs, culminating (in brightness) at the stars λ, ι Aquilæ (and η, R, β Scuti), curving round and partly enclosing a much fainter space to the north of it [agreeing with Heis]. There is a bright patch at about R. A. 18h. 10m., and S. Decl. 18° [shown by Heis]. Proceeding southwards the light gradually culminates at the stars δ, γ Sagittarii, where it suddenly diminishes in intensity [agreeing with Heis' drawing].

"A curious and complicated rift starts from near β Scuti, widens towards α Scuti, divides round an 'island' of dim light, and throws off a curious branch with three terminations; thence it becomes much narrower, and passes on by γ Scuti and μ Sagittarii, where it opens into a wide space, enclosing two small 'islands' of bright light and a larger one of faint nebulosity. The rift continues until it becomes

indistinguishable from the neighbouring haze, at about R. A. 16h. 45m., S. 22°, in which are two small patches of bright light.

"Near λ Scorpii is a black rift with three branches, one extending to κ, G Scorpii, another towards 45 Ophiuchi, and the third towards μ and ε Scorpii, bridged over at R. A. 16h. 58m., S. 35°, by a faint band of light. Three fairly bright condensations occur to the south-west of μ and ε Scorpii, the two northerly of these being partly surrounded by curious curved rifts. Between the latter of these and Lupus is a long rift extending from R. A. 15h. 50m., S. 52½°, to the neighbourhood of η Lupi. The southern end of this rift is separated by a 'bridge' of light from a well-defined and wider rift which reaches to α Centauri.

"It is at this point that the so-called great rift, or division of the Galaxy into two branches, is supposed to commence; but the division could never be recognised as such on Gould's maps, most of the space being filled up with faint light. [See remarks with reference to Herschel's drawing.]

"Between α Centauri and β Trianguli is a round black hole, in about R. A. 15h. 0m., S. 62½°. A faint band of light leaves the main stream of the Galaxy near δ Trianguli, and, sweeping round over α Trianguli, rejoins the main body near γ Trianguli. Between the latter star and Musca is a similar wisp of light.

"Round the well-known 'coal sack' near the Southern Cross the light is very bright, and so it continues till it reaches the vicinity of η Argûs. There are numerous condensations of nebulous light at various points in this region. The 'coal sack' itself is shown by Gould as filled with faint nebulosity, except in the northern end. [This agrees

with Sir John Herschel's telescopic observations already referred to, and shows clearly that the comparative blackness of the 'coal sack' is not absolute but relative, and really due to a paucity of stars in the interior.] A sharply defined narrow rift extends from the 'coal sack' to about R. A. 11h. 35m., S. 64° [not shown in Sir J. Herschel's drawing], at which point a curious square-shaped vacuity or region of faint light seems to cut into the bright light of the Galaxy [well shown by Herschel]. A small bright patch occurs at 10h. 2m., S. 59° 40′ (near q Carinæ).

"Between 10h. and 11h. R. A. it is difficult to say what is a rift, so involved are the fainter and brighter portions. The light gradually fades towards δ Velorum. A faint rift begins about 10h., S. 57°, and passing between N and κ Velorum curves round towards ϵ Carinæ. The well-known 'gap in Argo' is shown as a wide rift of faint light, cutting more or less across the Milky Way, and towards the north side enclosing or surrounding several 'islands' or patches of faint light. Near γ and ζ Argûs is a large roughly triangular area of bright light broken in upon by a faint rift.

"A curiously curved fringe of light extends from π to τ Puppis [following the course of a stream of fifth and sixth magnitude stars shown by Behrmann]. A long rift extends from about 8h. 50m., S. 42°, to 7h. 6m., S. 11°, where, in common with a much shorter and parallel rift (near δ Canis Majoris), it suddenly ends, apparently meeting another wedge-shaped rift somewhat at right angles to it. [The longer of these rifts agrees to some extent with one shown by Herschel and Heis.] Near ζ Puppis it sends off a well-defined rift, which bends round near β Pyxidis, and another, which extends to ξ Puppis. Near the latter star are two

circular holes filled with faint light. There is a curious S-shaped ray of light shown as enveloping the 'sword' and 'belt' of Orion." [This faint branch of the Galactic stream is also shown by Boeddicker and Heis.]

The best representation we now have of the northern portion of the Galaxy is a drawing recently completed by Dr. Otto Boeddicker, at Lord Rosse's Observatory, Ireland. This beautiful picture of the Milky Way, as seen with the naked eye in northern latitudes, is exquisitely drawn and evidently the work of an admirable observer and accomplished draftsman. At first sight it might perhaps seem open to one objection, and that is the extreme faintness of some of the less luminous portions of the Galactic Zone. But this could not have been avoided without giving to the brighter parts a greater prominence than a faithful representation of Nature would reasonably permit.

It must be remembered that even the brightest portions of the Milky Way are merely brilliant by contrast with the dark background of the heavens, and that even faint moonlight or slight haze is sufficient to totally obliterate its more delicate details. Even partial success in the delineation of so difficult an object would be in the highest degree creditable, and it will, I think, be admitted by those who have seen the original drawing that Dr. Boeddicker's success has been even greater than we might have expected from so excellent an astronomer.

A writer in the *Saturday Review* says his maps "are in many respects a completely new disclosure. Features barely suspected before come out in them as evident and persistent; every previous representation appears by comparison *structureless*. There is something of organic

regularity in the manner of divergence of innumerable branches from a knotted and gnarled trunk; nor can the protrusion of cloudy feelers towards outlying nebulæ and clusters be regarded as purposeless; while the fidelity with which the milky effulgence coils and sweeps along the lines laid down by the stars emblazoned upon it is perplexing if it be not significant."[1]

In the map of the Northern Hemisphere, showing the stars visible to the naked eye as given by Heis (Plate IV.), I have attempted to show the general outlines of the Milky Way as drawn by Boeddicker.

I am quite aware, however, that I have done very inadequate justice to Dr. Boeddicker's beautiful drawing. Its correct reproduction is quite beyond my powers as a draftsman.

The coincidence of streams of lucid stars with branches and sprays of Galactic light, as shown on Dr. Boeddicker's drawing, is, if not subjective, very remarkable and suggestive. A curved rift which runs from β Cephei to the Pole Star affords a remarkable instance of this association. The rift itself is nearly free from lucid stars, while the bounding nebulous light on both sides, particularly towards the north, contains many stars visible to the naked eye. This is especially noticeable at the point where the rift makes a sudden turn towards the Pole Star. At this point the inner (or northern) curve of the bend is well defined by the stars ψ, ω, 48, and 50 Cassiopeiæ. An enumeration I have made of the stars in Heis' Atlas, which will be considered presently, shows that this spot is more than usually rich in lucid stars. Other rich spots extend from

[1] *Saturday Review*, November 30th, 1889, p. 624.

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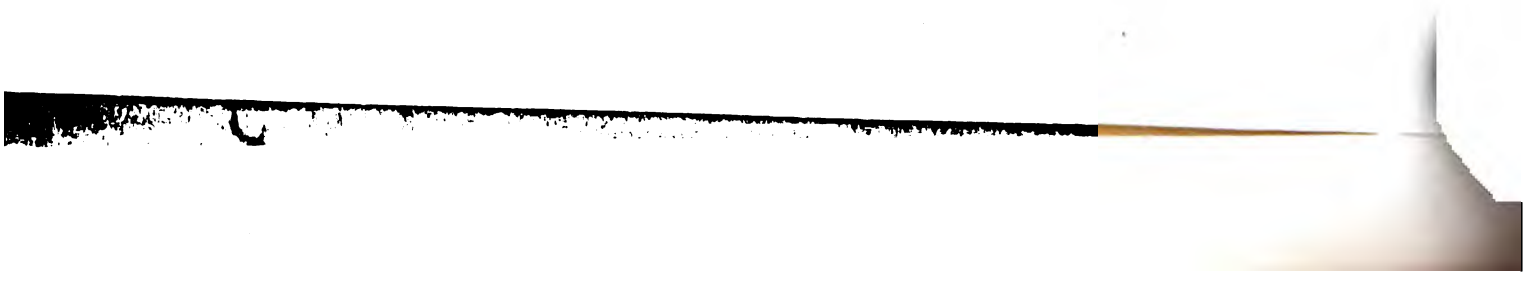

α to π Cephei, from α to o, and from ζ to β, and these coincide with the course of nebulous rays shown by Boeddicker.

A very faint curved ray extending from θ Cephei to ψ Cygni apparently follows a stream of small stars. A ray stretching from α to β Sagittæ towards the north, and involving δ, γ, η, and θ Sagittæ, is well defined by a stream of stars. Further examples of this coincidence of star streams and nebulous rays are found in a branch extending from κ Persei over Algol, and that from θ Persei to α and β Arietis. An examination of the drawing will show other instances of this remarkable association of Milky Way light with the stars visually projected on it,[1] an association which can hardly be due, in so many cases, to the effect of accident only, and evidently points to a real, and not merely an apparent, connection between the lucid stars and the Galaxy.

A curious curved branch of very faint light runs from near α Orionis, south of ζ Tauri, and following the stars o^1, o^2, π^1, π^2 π^3, π^4, π^5, and π^6, Orionis [I independently detected this faint stream, in the Punjab sky, in March 1873. See *Planetary and Stellar Studies*, p. 128]. This branch sends off a streamer to λ Orionis. Dr. Boeddicker also shows a faint S-shaped stream of light extending from the Milky Way, south of α Orionis, touching δ Orionis, and involving the "sword" of Orion. Faint nebulous light is also shown here by Heis and Gould, so that a connection between the Galaxy and the great nebula in Orion seems well established. Other faint streamers are also shown by Boeddicker between the Milky Way and Orion's "belt."

[1] The paucity of stars in the "coal sacks" and rifts will also be noticed.

A faint extension of nebulous light is also shown as stretching from Cassiopeia's Chair to the Great Nebula in Andromeda (31 Messier). This is a very interesting fact, for the actual connection of this wonderful object with the Milky Way has not, I think, been hitherto demonstrated. Heis shows no connecting branch. The Temporary Star of 1885, which appeared near the nucleus of this nebula in August of that year, is therefore no exception to the general rule that all phenomena of this kind have occurred in or close to the Galactic Zone.[1]

Sir William Herschel's telescopic gauges show that there is a well-marked relation between the general distribution of the stars and the course of the Milky Way, even as observed with the naked eye. Mr. Proctor was led to the same result by an examination of the stars visible to the naked eye only; but as he assumed the area of the heavens covered by the Galaxy as much smaller (about one-tenth of the whole sphere) than that shown by Heis and Gould,[2] his results are perhaps more strongly marked than is really the case in the sky. He also omitted vacuities which Heis shows to be filled in with nebulous light.

Sir J. Herschel also made a set of gauges in the Southern Hemisphere, and arrived at a conclusion in striking agreement with that obtained by his illustrious father. Both results will be found in the Appendix to this volume (Note D), and show conclusively that the number of visible stars increases as we proceed from the poles of the Galaxy

[1] The *only* exception—at least, in modern times—seems to be the "Blaze Star" of 1866 in Corona Borealis.

[2] It should be stated, however, that Houzeau's drawing gives, according to Plassmann, an area of about one-tenth of the sphere.

towards the Milky Way, where the maximum number is found.

Houzeau finds that the Northern Hemisphere is slightly richer in naked-eye stars than the Southern by more than 100 stars, and he considers this fact to have a real and not merely a fictitious existence. He found the following numbers of lucid stars for each hemisphere :—

Northern . . .	2916
Southern . . .	2803
Total . .	5719 stars.

and says: "Je regarde donc comme un fait acquis qu'à égalité de circonstances, c'est-à-dire par des observations faites de même manière et comparable entre elles, l'hémisphère sud renferme un peu moins d'étoiles visibles à l'œil nu que l'hémisphère nord."

Examining the distribution of the lucid stars with reference to the plane of the Sun's equator Houzeau finds no well-marked relation. He gives a statistical enumeration of the stars in both hemispheres, and says: "En considérant les chiffres de la dernière colonne, on accordera, je pense, qu'il n'y a aucune raison de supposer que la distribution des étoiles invisibles[1] à l'œil nu ait un rapport systématique avec la situation de l'équateur du soleil. Cette conclusion est d'accord avec les idées théoretiques dans les quelles on regarde les étoiles comme étrangères à la nébuleuse solaire. Il n'y en a pas moins un certain intérêt à établir cette indépendance sur la base des faits."

He also investigates the question as to whether the dis-

[1] *Sic* in original, probably a misprint for *visibles*.

tribution of the lucid stars shows any relation to the direction towards which the Solar System is moving in space,[1] and arrives at a negative conclusion. For the direction at right angles to that of the solar motion he finds a similar result. He then examines the relation of the lucid stars with reference to the Milky Way itself. Adopting his own position of the Northern Pole of the Milky Way (given above), and dividing the sphere into zones of 20° by concentric circles drawn round the Northern and Southern Galactic Poles, he makes an enumeration of the stars contained in each zone (see Appendix, Note E), and arrives at the result that the lucid stars show a marked tendency to aggregation on the Milky Way, the density increasing from 0·113 per square degree in the zone surrounding the Northern Galactic Pole, to 0·160 on the Milky Way, and diminishing again to 0·123 at the Southern Pole.

This result confirms that found by Sir W. Herschel, and by F. Struve in his *Études d'Astronomie Stellaire*. It also agrees with Proctor's researches, and with the results I have found myself from an examination of the Atlases of Behrmann, Heis, and Houzeau—results which will be considered presently.

Struve found that the law of condensation of stars as we approach the Milky Way is more marked in the case of the telescopic stars than for those visible to the naked eye. To ascertain whether this concentration increases regularly in the inverse ratio of stellar brightness, Houzeau divides the lucid stars observed by him into two classes, the first containing the stars of magnitudes 1, 2, and 3, and the second

[1] For the position of this point he adopts Otto Struve's result, viz., R. A. 17h. 19·8m., Decl. N. 34° 31′ (1880).

of magnitudes 4, 5, and 6. (The first contains 271 stars, and the latter 5448.) The united areas of the two circumpolar caps being exactly equal to the area of the middle (or Galactic Zone), he finds that for 100 stars of the first 3 magnitudes contained in the caps there are 138 in the middle zone, while for 100 stars of magnitudes 4, 5, and 6 in the same caps there are only 122 in the middle zone; thus giving the unexpected result that the condensation of stars on the Milky Way is more marked for the bright stars than for the fainter ones.

With reference to the difference between this result and that found by Struve, Houzeau says: "En admettant avec F. Struve que pour les étoiles télescopiques l'effet de concentration est d'autant plus marqué que l'éclat de ces astres est moindre, il en résulterait ce fait remarquable, que les étoiles les plus brillants et les étoiles les plus faibles sont celles qui se montrent le plus soumises à l'influence de la Voie Lactée; tandis que celles d'un éclat moyen, vers la limite de la visibilité à l'œil nu, en soit les plus affranchies."

Considering, however, the small number of stars of the brighter magnitudes on which this conclusion is founded, Houzeau's result should perhaps be accepted with some reserve.[1]

To test whether the tendency of the stars to crowd on the Milky Way is shown by the naked-eye stars as well as by those visible in larger telescopes, I have made a careful enumeration of the stars shown in the Atlases of Behrmann, Heis, and Houzeau, which are fairly complete for stars visible to ordinary eyesight. The total number of stars

[1] Attention was directed to this point by M. le Général Liagre in an introductory report to Houzeau's work.

shown by Houzeau in both hemispheres is, according to his own statement, 5719. Now, according to Plassmann's computation of the area covered by Milky Way light in Houzeau's maps, the number due to this area is $5719 \times 0{\cdot}1055 = 580{\cdot}76$.

By a careful enumeration of the stars shown by Houzeau as lying on the Milky Way (omitting those which merely touch its boundaries), I find a total of 706, or a marked excess of lucid stars on the Milky Way above that due to its area.

Heis' maps extend from the North Pole to about 30° South Declination (or a little farther south), and those of Behrmann from the South Pole to 20° South Declination (or a little farther north). Heis shows all stars to 6-7 magnitude (6·33), and Behrmann all stars to 6th magnitude. As, however, some of Behrmann's 6th-magnitude stars are somewhat fainter than 6th magnitude we may perhaps consider the two Atlases as fairly comparable.[1] In the portion of the sky common to both Atlases (20° to 30° S. Decl.) I find that some small stars shown by Behrmann are omitted by Heis, and *vice versa*; but these are exceptions, and will not materially affect the general result. As Behrmann omits the Milky Way altogether in his maps, its course with reference to the stars shown by him has been derived from Sir John Herschel's delineation.

[1] From a comparison of the magnitudes of the *Uranometria Argentina* with those given by Behrmann, Dr. Gould finds that some of Behrmann's magnitudes include stars of various degrees of brilliancy, and are therefore not reliable as regards the actual magnitude of any *individual* star. But as I have not, in my enumeration of Behrmann's stars, taken into account relative magnitudes, this will not influence my results. With reference to general *stellar distribution*, it is evident that Behrmann's maps are fairly comparable *inter se*.

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The enumeration was made in divisions of 10° in R. A. and 10° in Decl., as shown in the Atlases referred to. The area of these divisions can be easily determined (see Appendix, Note F), and thus the relative richness or poorness of the various regions of the sky may be ascertained. The numerical results are shown in the accompanying diagrams[1] (Plates VI. and VII.). I have also ascertained the number of stars of each magnitude as given in the catalogues of Heis, the *Uranometria Argentina*, the *Uranometria Nova Oxoniensis*, and the *Harvard Photometry*, and the results will be found in the Appendix (Note G).[2]

I find that the total number of stars shown by Heis as visible to the naked eye *north* of the Equator (excluding variable stars, clusters, and nebulæ) is 3903, and the total number of stars on the Milky Way and its branches (including vacuities in which Heis shows faint light) is 1199, or 30·7 per cent. of the whole. The Milky Way—as drawn by Heis—covers, I find, an area of 5340 square degrees, or 25·88 per cent. of the Northern Hemisphere (20,626·5 square degrees), so that the number of naked-eye stars on the Milky Way is slightly in excess of that due to its area. Had I omitted the vacuities, as Proctor has done, the proportion would probably have been somewhat increased, as a glance at Heis' maps is sufficient to show that the lucid stars are somewhat sparsely scattered over these (so-called) vacuities.

The number of lucid stars shown by Heis in the Northern

[1] In these diagrams the rich regions are coloured blue; the richer the region the deeper the tint.

[2] The results given for the *Harvard Photometry* are due to Mr. Monck.

Hemisphere gives an average of 0·189 per square degree, or 5·29 square degrees to each star (about 23 times the apparent area of the full moon). For the area of the Southern Hemisphere included in Behrmann's maps the number of stars is 2306, giving an average of about 0·17 per square degree, or nearly 6 square degrees to each star; showing that the naked-eye stars are very thinly scattered over the surface of the heavens.[1]

The stars in Dr. Gould's charts (*Uranometria Argentina*) number (to the 7th magnitude inclusive) 6694 south of the Equator. This gives 0·324 per square degree, or about 3·09 square degrees to each star (Plate VIII.).

The richest spot in the Northern Hemisphere is, of course, the Pleiades, where the 6 stars visible to average eyesight are included in a space of slightly less than one square degree. But as the Pleiades clearly form a distinct cluster they must be considered as an exception to the general rule. Excluding the Pleiades I find that the richest spots in lucid stars north of the Equator are: between Lacerta and ι, κ Andromedæ (see Fig. 1); between α, β Cephei and the region including the head of Cepheus, which give an average of about 0·45 stars per square degree (or nearly 2½ times the average for the whole hemisphere); and the region including the chief stars of Lyra (Vega, etc.), which gives about the same average.

Another rich spot covers the Chair of Cassiopeia, and extends over ϵ and ψ Cassiopeiæ towards the North Pole. This gives an average of about 0·36 per square degree. The spots in Cepheus and Cassiopeia are situated in the

[1] Even one star to each area equal to that of the full moon would give a total of about 184,000 stars for both hemispheres!

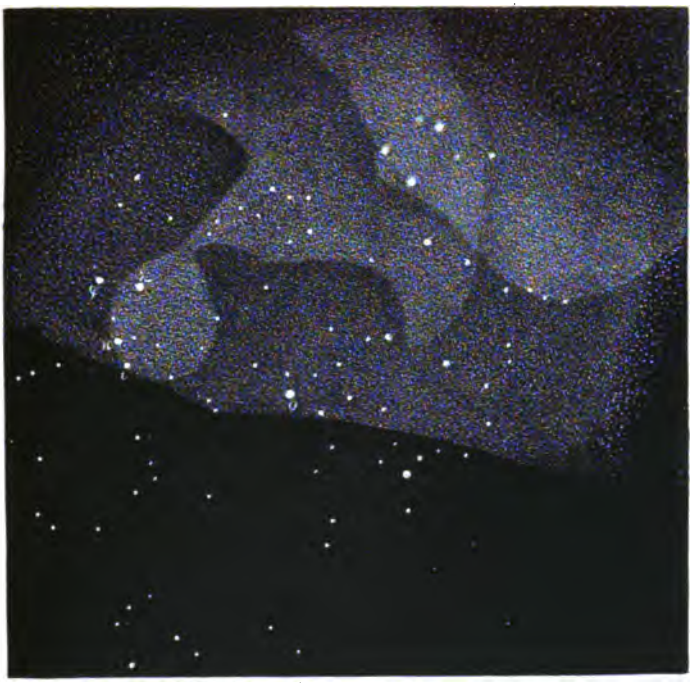

Fig. 1.
Rich and poor regions in Andromeda and Lacerta, and Milky Way from Iris

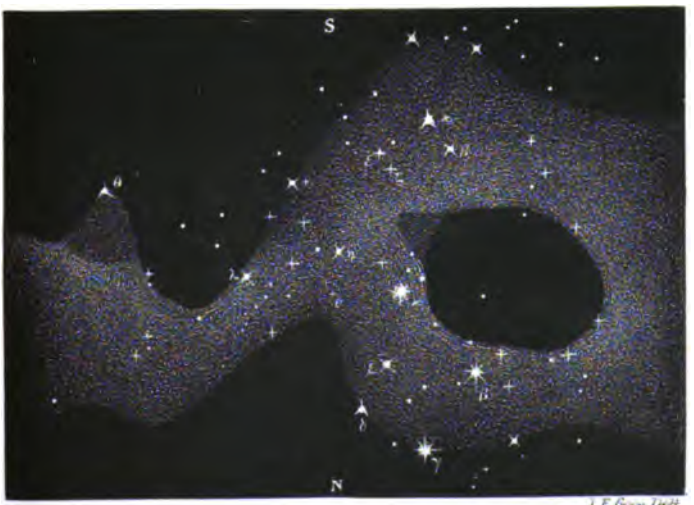

Fig. 2.
Rich region near the Southern Cross from Behrmann.
Milky Way from Sir J. Herschel

expansion of the Milky Way which stretches from Andromeda towards the Pole Star. The spot in Lyra is also included in the Milky Way, as drawn by Heis. Closely following the rich spot in Cassiopeia (between ι Cassiopeiæ and η Persei) is a remarkably poor region where a space of some 60 square degrees does not contain a single star brighter than the 6th magnitude! Another pretty rich spot includes α, γ, ν, ξ, ρ, π^1, π^2, o, and ω Cygni. The Hyades also form a rich region; but these may also—like the Pleiades—be considered as forming an open cluster.

An extensive region of more than average richness covers Gemini, a portion of Taurus (including the Hyades), Orion, and the head and fore feet of Monoceros, and is connected with the rich southern region to be described further on.

In addition to the poor spot in Cassiopeia referred to above may be mentioned that including the body and fore legs of Camelopardus and the ears of the Lynx. Immediately south of this is a pretty rich region, which includes δ and ξ Aurigæ. Another poor region occurs in Pisces (between δ and ω Piscium); another north of δ Ursæ Majoris (the faintest star of the "Plough") and between that star and κ Draconis; one between Coma Berenices, ξ Ursæ, and δ Leonis, and others less remarkable. It is worthy of remark here that the Northern Pole of the Milky Way lies close to Coma Berenices, which forms a rich region; but this also may be considered as a loose cluster, like the Hyades.

South of the Equator Heis' maps show the northern rich region above described, extending over Lepus and Canis Major, and Behrmann's maps carry it south over Columba and Argo to the Southern Cross. The existence of this rich

southern region was strongly maintained by the late Mr. Proctor,[1] but has been doubted by some astronomers, and distinctly denied by Mr. Henry Farquhar some years since.[2] A mere glance, however, at Behrmann's maps is sufficient to show that such a rich region really exists, and a statistical enumeration confirms the judgment of the eye (see Plate VII.).

It will not do to argue, as Mr. Farquhar does, that the apparent richness found by Proctor is due to the fact that "those who observed this part of the heavens included more and fainter stars in their sixth magnitude than did northern observers." This argument would apply to the whole of the southern sky, but I find that the region referred to *is* rich in lucid stars—not by comparison with the Northern Hemisphere, but with reference to *the other portions of Behrmann's maps*. This seems decisive as to the existence of the rich region in question.

This region nearly coincides with the course of the Milky Way from Canis Major to the Southern Cross, and includes within its boundaries a very rich spot about midway between η Argûs (the famous variable star) and Canopus (α Argûs). This spot includes ϵ, ι, and χ Carinæ (average richness about 0·57). Most of the stars are, however, small. A still richer region, but of smaller area, lies between ϵ Canis Majoris and β, θ Columbæ.

The richest spot, however, in the Southern Hemisphere of any considerable size, and containing bright stars, is that situated immediately south preceding the Southern Cross, and including α, η, ζ, θ Crucis, and α, β, ϵ, ζ Muscæ (see Fig. 2). It lies on the Milky Way, and its close

[1] *Essays on Astronomy*, p. 312. [2] *Observatory*, December 1879.

proximity to the barren "coal sack"—in which Behrmann shows only two small lucid stars—is very remarkable and suggestive. It has an average of 0·6 to the square degree, or three stars to five square degrees.

There are some other rich regions in the Southern Hemisphere, unconnected with the Milky Way, of which the most remarkable is a spot just north of δ, ϵ, ζ Hydri,

Fig. 3.—Region rich in lucid stars. From Behrmann's Atlas.

on the borders of Hydrus and Horologium (see Fig. 3). This is *especially* rich, as shown by Behrmann, but the stars are mostly small—several of them, indeed, below the sixth magnitude, according to the *Uranometria Argentina.*

A tolerably rich, but very elongated region extends from near ρ Argûs (about 25° S. Decl.) up to α and δ Antliæ (see Fig. 4); but the stars are mostly small, and probably

would not, to average eyes, convey an impression of richness. Immediately south of this is a very poor region, in which over an area of about a hundred square degrees Behrmann does not show a single star!—another example

Fig. 4.—Rich and poor regions in Hydra and Antlia. From Behrmann.

of rich and poor regions in close proximity. Another isolated region, above the average richness, includes η, ζ, μ, ν, ϕ, χ Centauri, and α, β, γ, δ, ϵ, ι, μ, ν, π, etc., Lupi (see Fig. 5). This region lies near the borders of the Milky Way extension in Norma.

Another very poor region lies between ω, ψ, and σ

Fig. 5.—Rich region in Centaurus and Lupus. From Behrmann.

Capricorni on the one side, and ω, 62, etc., Sagittarii on the other. An especially poor region—according to both Behrmann and Heis—extends from η Ceti south, past β Ceti, to α Sculptoris. Even in Klein's maps[1] (S.P.C.K.), which show stars to $6\frac{1}{2}$ magnitude, there are only four small stars in this area, which includes the South Pole of the Milky Way (about 3° north of α Sculptoris). Another blank space extends from Triangulum Australis, past β Apodis, to μ Octantis, and another—not quite so poor—lies between α and ϵ Tucanæ.

From a discussion of the observations made at Cordova for the *Uranometria Argentina* Dr. Gould concludes that "a belt or stream of bright stars appears to girdle the heavens very nearly in a great circle, which intersects the Milky Way at about the points of its highest declination, and forms with it an angle not far from 20°; the southern node being near the margin of the Cross, and the northern in Cassiopeia." According to Gould this belt covers Orion, Canis Major, Columba, Puppis, Carina, Crux (thus following the rich southern region above referred to), Centaurus, Lupus, and the head of Scorpio, its northern course being "indicated by the brightest stars in *Taurus*, *Perseus*, *Cassiopeia*, *Cepheus*, *Cygnus*, and *Lyra*."

The southern portion of this stream was previously recognised by Sir John Herschel, who says (*Cape Observations*, p. 385): "It is about this region, or perhaps somewhat earlier, in the interval between η Argûs and α Crucis, that the Galactic Circle, or medial line of the Milky Way, may be considered as crossed by that zone of large stars which is marked out by the brilliant

[1] Published in 1888.

constellation of *Orion*, the bright stars of Canis Major, and almost all the more conspicuous stars of *Argo*, the Cross, the Centaur, *Lupus*, and *Scorpio*. A great circle passing through *ε Orionis* and *α Crucis* will mark out the axis of the zone in question, whose inclination to the galactic circle is therefore about 20°, and whose appearance would lead us to suspect that our nearest neighbours in the sidereal system (if really such) form part of a subordinate sheet or stratum, deviating to that extent from parallelism to the general mass which, seen projected on the heavens, forms the Milky Way."

Dr. Gould comes to a similar conclusion, and says (*Uranometria Argentina*, p. 355): "I cannot avoid the conviction that our own system forms part of a small cluster, distinct from the vast organisation of that which forms the Milky Way, and of a flattened and somewhat bifid form. This cluster may perhaps be comparable with the Pleiades, since by a crude estimate it would seem to consist of less than 500 stars."

Photography, however, shows that the Pleiades include—apparently, at least—over 2000 stars, and its general shape would lead us to imagine that it much more closely resembles the "globular clusters" than any belt or zone of stars.

I cannot see that Dr. Gould's "belt of bright stars" is at all strikingly marked—at least in the Northern Hemisphere; and Gould himself admits that it is "scarcely traceable in Ophiuchus, and widely and confusedly resolved and spread out through *Cygnus*, *Lacerta*, and *Cepheus*." The apparent connection of the bright stars with the Milky Way itself seems to me almost as clearly defined. It must be admitted, however, that the position of Orion, the

Hyades, the Pleiades, and Lyra seems in favour of Dr. Gould's theory.

On the other hand, Dr. Gould's own maps show that Orion is covered with faint nebulous light (partly shown by Boeddicker and Heis) ; and, according to Heis, Lyra is involved in the Milky Way. The Hyades and Pleiades would therefore seem to be the principal outstanding stars, but even these are shown by Boeddicker to be connected with the Galaxy by faint streams of light. Sir John Herschel's argument with reference to the probably globular shape of the Magellanic Clouds seems also applicable to the Pleiades, which, according to the Paris photograph, contains stars of all orders of brightness from the third to the seventeenth magnitudes.

In an interesting article in *Knowledge* for July 1891, Mr. J. R. Sutton advocates the theory that the Galaxy consists of "a great ring of large stars"—Gould's solar cluster—"intersecting an equal ring of small ones"—the Milky Way—"at the extremities of a common diameter." He considers that "the great star belt is a genuine girdle of stars in space ; in which, also, the foundations of the sidereal system are laid, the Milky Way being an appendant to it, of lesser rank."

The chief objection to this view seems to be that most of the stars in Gould's star belt lie on the Milky Way and its branches as depicted by Boeddicker and Gould. There seems, therefore, no good grounds for considering the so-called star belt as *necessarily distinct* from the Milky Way. It is only on star maps in which the Milky Way is insufficiently delineated that there is any well-marked distinction between the two streams.

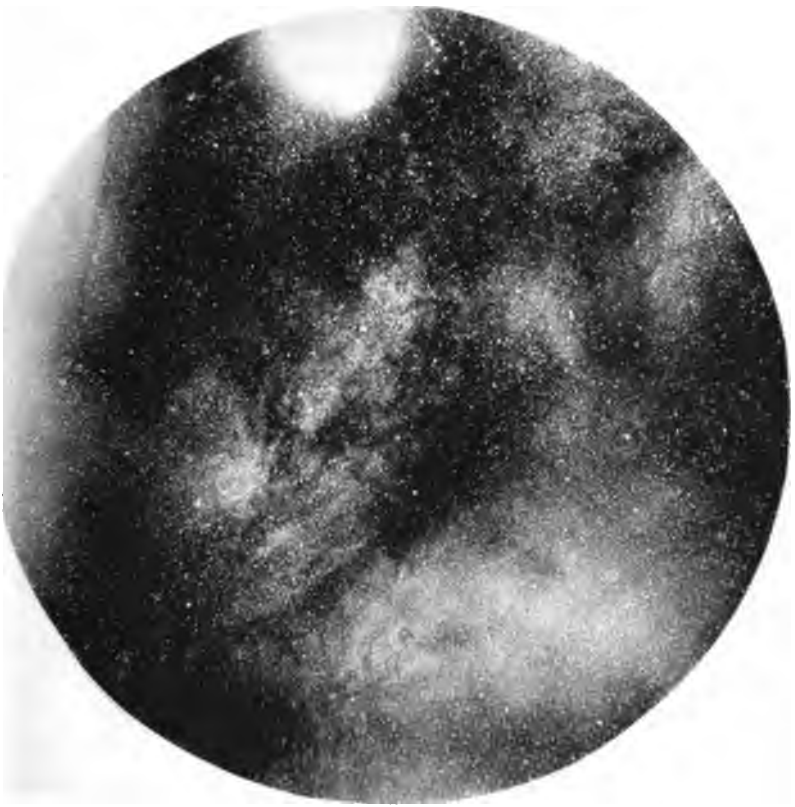

PLATE IX.

Photograph of the Milky Way in Sagittarius.
R.A. 17h. 56m., S. Dec. 28°.

Taken with 6-inch portrait lens by Prof. E. E. BARNARD, at the Lick Observatory (1889). Reproduced from an original glass positive.

The white spot at top of plate is the over-exposed image of the planet Jupiter.

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Some beautiful photographs have recently been taken of the Milky Way in Sagittarius by Mr. Barnard of the Lick Observatory. Two of these are reproduced in Plates IX. and X. from glass positives, kindly sent to me by Mr. Barnard to be used as illustrations in the present work.

Photographs recently taken by Mr. H. C. Russell, F.R.S., at Sydney, New South Wales, with a 6-inch portrait lens, show some remarkable features in the Southern Milky Way and Magellanic Clouds. An exposure of 4½ hours shows the structure of the Nubecula Major, or greater Magellanic Cloud, to be that of "a complex spiral nebula with two centres"; and a structure somewhat similar to that of the Dumb Bell nebula is visible in the Nubecula Minor. The photographs show that the whole of the stars in the Southern Cross are "fully involved in the Milky Way, and the Coal Sack, instead of being a closed space, is seen to be open on the south side. . . . It also appears that stars are very numerous over three-fourths of it, and that it is only in the extreme north of it that we find that absence of stars which would justify the name."[1]

This confirms the existence of the faint nebulosity shown by Dr. Gould in the interior of the Coal Sack. Mr. Russell says: "The Coal Sack is seen to extend in relatively dark marking towards and north of *β Centauri*, where it terminates in a space which seems to be absolutely void of stars in a number of photographs which have been taken from it."[1]

With reference to the Milky Way surrounding γ^2 Sagittarii he says that, when the negative of this region is "examined by the aid of an eye-glass, some of the extra-

[1] *Monthly Notices*, R.A.S., Vol. LI., No. 1 (November 1890).

ordinary details found in this part of the Milky Way, and which is very unlike what I have found in other parts, will be seen. It seems as if one were looking at curve after curve found farther and farther back in the infinity beyond, like eddies in an infinitely complex vortex,[1] till they end in faint nebulous points of light, which can only just make themselves known after four hours of steady impact on the sensitive film."

Some beautiful photographs of the Milky Way near a Cygni were obtained in 1891 by Dr. Max Wolf of Heidelberg, using a camera of about $5\frac{1}{4}$ inches aperture and $30\frac{1}{3}$ inches focus. These show, in addition to thousands of small stars, a mass of nebulous light north of ξ Cygni, and the stars a and γ Cygni surrounded by nebulosity. These photographs clearly indicate that the bright and faint stars are closely associated and probably involved in the nebulous light.[2]

Professor Pickering finds that the majority of the brighter stars in the Milky Way show spectra of the first or Sirian type. I have made a careful enumeration of the stars contained in the Draper Catalogue of Stellar Spectra which lie on the Milky Way and its branches, as drawn by Heis, and find that out of 3061 stars 1940, or 63·4 per cent., are of the first type.[3]

As Mr. Monck has pointed out, the fact of stars of the first or Sirian type being probably brighter, surface for surface, than those of the second or solar type would sug-

[1] See *The Scenery of the Heavens*, p. 272, where (writing in 1889) I suggested a "vortex ring" structure of the Galaxy.

[2] See a paper by Mr. Ranyard in *Knowledge*, October 1891.

[3] *Journal of the British Astronomical Association*, December 1891.

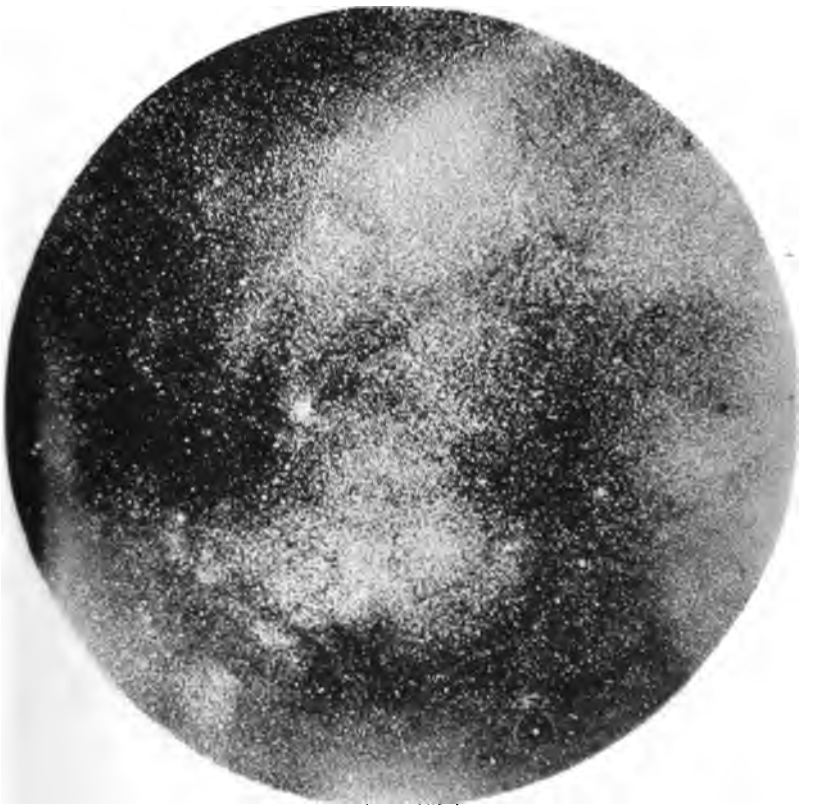

PLATE X.

Photograph of the Milky Way near 11 Messier (in Aquila).

Taken by Prof. E. E. BARNARD, of the Lick Observatory (1889).

(From an original glass positive.)

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gest that stars of the first type would be visible at greater distances than those of the second. I find that the great majority of the stars having large proper motions—a stellar feature generally supposed to indicate proximity to our system—have spectra to the second type,[1] and this is of course evidence in favour of Mr. Monck's view.

The preponderance of first-type stars in the Milky Way would therefore suggest that it lies farther from us than the generality of the visible stars—a conclusion which has previously been arrived at from other considerations.

It does not follow, however, that the fainter stars of the Galaxy lie at a *vastly* greater distance than some of the brighter stars—for instance, α Centauri and 61 Cygni—which are optically, at least, connected with it. Indeed, Dr. Wolf's photographs—above referred to—suggest that some bright stars, like α and γ Cygni, are actually involved in the nebulous light of the Milky Way.

[1] *Astronomy and Astro-Physics*, January 1892.

CHAPTER X.

CLUSTERING STARS AND STAR STREAMS.

"Clusters and beds of worlds, and bee-like swarms
Of suns and starry streams."

TENNYSON.

THE general tendency of the stars to aggregate into groups, more or less marked, is perhaps indicated by their ancient division into constellation figures. In the Northern Hemisphere we have the well-known groups of "The Plough" (Ursa Major) "Cassiopeia's Chair," "The Sickle" in Leo, Corona Borealis, and Orion; and in the Southern Hemisphere the Southern Cross, Scorpio, Corvus, etc. The "Dolphin's Rhomb," the head of Hydra, and the group near 70 Ophiuchi also form examples of this clustering tendency.

That in some of these at least the connection is real, and not merely apparent, is shown by the community of "proper motions" discovered by Proctor among the five stars of the "Plough," β, γ, δ, ϵ, and ζ—a connection afterwards verified by Dr. Huggins with the spectroscope; and also in several of the stars in "Cassiopeia's Chair," which seem to be moving in the same general direction through space. Among the lucid stars, however, the most remarkable examples of this clustering tendency are found in the

smaller groups, such as the Hyades and Pleiades. In the latter well-known cluster—perhaps the most remarkable group of stars in the heavens—six stars are visible to ordinary eyesight; but some persons gifted with keener vision can see a larger number.[1]

There is a tradition that seven stars were originally visible to average eyes, but that one disappeared at the taking of Troy. With reference to this supposed disappearance of the "lost Pleiad," Professor Pickering has recently discovered that the spectrum of Pleione (which forms a wide pair with Atlas) bears a striking resemblance to that of P (34) Cygni, the so-called "Temporary Star of 1600." The similarity of the spectra suggests that Pleione may, like the star in Cygnus, be subject to occasional fluctuations of light, which may perhaps account for its possible visibility to the naked eye in ancient times. Examined with a telescope the Pleiades show an enormously increased number of stars—even with an opera-glass a considerable number may be seen; and in a photograph of the group recently taken at the Paris Observatory, with an exposure of three hours, no less than 2326 stars can readily be counted in a space of about three square degrees!

In this remarkable picture smaller aggregations of stars are visible: for instance, Alcyone, the brightest of the whole group, forms one of a small cluster of some ten stars, and Maia and Merope have several faint stars near them.

The Hyades also form a remarkable naked-eye group, with the brilliant red star Aldebaran as their leader; but

[1] Miss Airy, daughter of the late Astronomer Royal, is said to have seen twelve, and Möstlin (according to Kepler) fourteen.

the component stars are not so closely crowded, and I am not aware whether the group has yet been photographed.

An interesting but more scattered group of lucid stars will be found near *a* Persei, forming a curved line or festoon of stars. Another well-known cluster is the Præsepe, or the "Beehive," in Cancer. The stars composing it are, however, scarcely perceptible to the naked eye, and in ancient times this cluster, from its nebulous

Fig. 6.—Curious group of stars near 4 Vulpeculæ, as seen with a 2-inch telescope, October 1889.

aspect, was probably ranked as a nebula, and perhaps placed in the same class with the great nebula in Andromeda, which was also known to the earlier astronomers.

Coma Berenices is another example of a scattered cluster.

Among clusters a little beyond the limits of naked-eye vision there are many interesting examples of star clustering which may be seen with a binocular or good opera-glass. One of the most remarkable of these is that surrounding the star 5 Vulpecula. I give two drawings of

Fig. 7.—The star group near 4 Vulpeculæ, as seen by Espin with 17½-inch reflector, power 70, November 9th, 1889. Stars to 10½ magnitude.

this curious little asterism, one (Fig. 6) as seen by myself with a 2-inch telescope, and the other (Fig. 7) as seen by Mr. Espin with a reflecting telescope of 17¼ inches aperture. The tendency of the brighter stars to run in lines will be noticed, and the curious grouping of fainter stars towards the left of the larger diagram is also remarkable. This group should be photographed. It is surrounded by Milky Way light, according to both Boeddicker and Heis.

About 2¾ degrees *preceding* the bright star Pollux I see a small cluster of stars, of about the seventh and eighth magnitudes, which, with a binocular field-glass, very much resembles the Pleiades as seen with the naked eye.

The stars 10, 11, and 12 Geminorum (north preceding μ Geminorum) also lie in a small cluster of stars which may be well seen with a binocular.

Surrounding the star 12 Monocerotis is a cluster of stars of the seventh magnitude and fainter.

The well-known double cluster near χ Persei may be seen with an opera-glass, but a telescope is necessary to see the component stars, and the larger the instrument the greater the number of stars visible in these wonderful objects. They have been well photographed at the Paris Observatory, and also by Mr. Roberts at Liverpool. On these photographs the clusters are clearly resolved, with no trace of outstanding nebulosity, suggesting that the component stars are probably at nearly the same distance from the earth.

The cluster 39 Messier between π^1 and 71 Cygni may be well seen with a binocular field-glass, in which it somewhat resembles the Pleiades as seen with the naked eye.

Another fine open cluster will be found a little north following β Ophiuchi. Between β and γ Ophiuchi is a remarkably blank spot. On August 15th, 1890, I failed to glimpse the faintest star with binocular in a clear moonless sky—a striking contrast to the rich region north of β. A similar blank space will be found just north of the stars π and ϕ Aquilæ (north of Altair). On September 3rd, 1886, I could only see glimpses of *very* faint stars with the binocular in a clear moonless sky—a remarkable vacuity *so close* to a region of bright stars, and a good example of an interesting stellar feature, namely, rich and poor regions in close proximity.

I may here mention that a region of considerable extent remarkably barren of bright stars will be noticed with the naked eye in the Northern Hemisphere. This comparatively poor region, which contains no star brighter than the fourth magnitude, is bounded by Cepheus, Cassiopeia, Perseus, Auriga, Gemini, Ursa Major, Draco, and Ursa Minor, and forms a conspicuous feature in the north-eastern portion of the sky in the early winter evenings. It will be noticed that the bounding constellations all contain bright stars.

Examined with a telescope the heavens afford numerous instances of stellar aggregation. The Milky Way forms, of course, the most remarkable example—on a great scale; but among comparatively isolated groups there are numerous interesting examples. Some of the most remarkable of these are described in my *Scenery of the Heavens* (pp. 213-17). Of these the cluster known as 35 Messier—a little north of the variable star η Geminorum—is visible in an opera-glass, but a small telescope is required

to see the component stars. A beautiful photograph of this cluster has been taken at the Paris Observatory. A paper print from the original negative lies before me as I write.[1] A well-marked clustering tendency is visible among the brighter stars of the group, two, three, four, and sometimes five stars being grouped together in subordinate clusterings.

In the Southern Hemisphere a splendid cluster of small stars surrounds the star κ Crucis. Sir John Herschel charted 110 stars to the seventh magnitude and fainter. The component stars are of different colours, red, greenish, bluish, which he says "give it the effect of a superb piece of fancy jewellery." It lies near the northern edge of the well-known "coal sack," and Dr. Gould says of it: "The exquisitely beautiful cluster κ *Crucis* contains a large number of stars of various tints and hues, contrasting wonderfully with each other, when viewed with a telescope of large aperture."[2] Mr. Russell's drawing of this cluster, made in 1872, shows some well-marked star streams.

Just north of ζ Scorpii is a bright cluster which I found visible to the naked eye in the Punjab sky as a hazy star of about magnitude $4\frac{1}{2}$. With a 3-inch refractor the component stars were well seen.

The so-called "globular clusters" form excellent examples of the clustering tendency, but here the component stars lie so close together that their physical connection cannot be doubted.

Among groups of stars not usually classed as clusters

[1] A reduced copy of this photograph will be found in the work above referred to (p. 213).

[2] *Uranometria Argentina*, p. 269.

PLATE XI.

Photograph of a portion of Gemini.

Taken March 14, 1887, by M. M. HENRY, at the Paris Observatory.

(From an original paper print.)

there are many examples of this aggregating tendency visible on the stellar photographs taken at the Paris Observatory. Photographs of portions of the Milky Way in Cassiopeia, Gemini, and Lyra show the small stars to be in many places, not scattered uniformly, but with a marked tendency to cluster into subordinate groups adjoining comparatively starless spaces. This is especially noticeable on a photograph of a portion of Gemini (R. A. 6h. 10m., N. 20° 20′) a little south of η Geminorum (Plate XI.). On these photographs many cases occur in which three, four, or more stars are grouped together, often in a straight line, or nearly so, and to all appearance comparatively isolated from their surrounding neighbours. On a photograph of a rich Milky Way region in Cygnus (R. A. 19h. 45m., N. 35° 30′), taken by Mr. Roberts at Liverpool with an exposure of 60 minutes, on which no less than 16,206 stars may be counted (on an area of about four square degrees), similar features are noticeable.

In his observations of the Milky Way in the Southern Hemisphere, Sir John Herschel says: "Here [R. A. 17h. 50m., S. 33°—36°] the Milky Way is composed of separate, or slightly, or strongly connected clouds of semi-nebulous light; and as the telescope moves, the appearance is that of clouds passing in a *scud* as the sailors call it." "I could fill a catalogue with the clusters of the 6th class which are here. The Milky Way is like sand, not strewn evenly as with a sieve, but as if flung down by handfuls (and both hands at once), leaving dark intervals, and all consisting of stars 14 . . . 16 . . . 20m., down to nebulosity, in a most astonishing manner."[1]

[1] *Cape Observations*, p. 388.

No. 2908. "Cluster 7th class. The 2nd of two stars 9m. which may be considered the leading stars of the very large and fine cluster of the Nubecula Major, which fills many fields, is of all degrees of condensation and much broken up into groups and patches. . . . The field full of grouping stars."

In Proctor's chart of 324,198 stars the clustering tendency is well marked. So many cases as this chart discloses

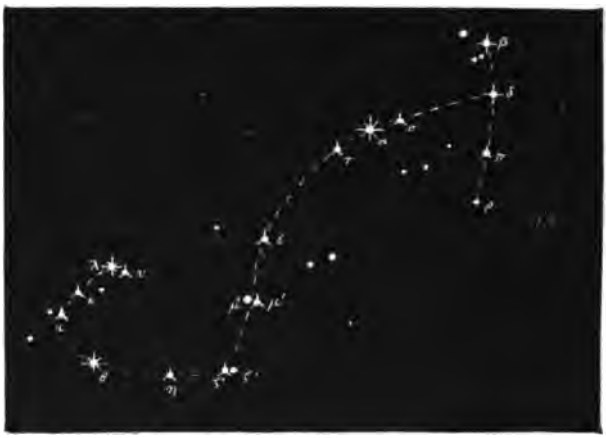

Fig. 8.—Stream of bright stars in Scorpio.

can hardly be due merely to the effect of accidental arrangement.

The tendency of the stars to run in streams is pointed out by Proctor in his *Universe and the Coming Transits* (first two chapters). Among the lucid stars the most remarkable instances of this stream-forming tendency are found in Pisces, Scorpio, the "River Eridanus," the streams in Aquarius, and the festoon of stars formed by η, γ, α, δ, and μ Persei.

The stream forming the constellation Eridanus was noticed by the ancients (as the name "river" implies); but in this case the stars are so far apart that the connection is probably more apparent than real. Perhaps the same may be said of the streams forming Scorpio and Pisces; but still the streams are sufficiently well defined to attract even the

Fig. 9.—Star streams in Lyra and Cygnus. Stars to 6½ magnitude.

eye of a casual observer (see Fig. 8). Other examples of the kind may be seen in Corona Borealis, or the Northern Crown; in Corona Australis in the Southern Hemisphere; and also among fainter stars visible to the naked eye or with an opera-glass. Examples of some of these streams, whether apparent or real, are given in the accompanying diagrams (Figs. 9, 10, and 11).

But it is among the still fainter stars—those visible only with a telescope, or revealed by photography—that we find the most striking examples of this stream-forming tendency. In these cases the small stars composing the streams are comparatively close together—at least, apparently so—and

Fig. 10.—Group of stars in Taurus, showing streams as seen with an opera-glass.

for this reason the evidence in favour of a real physical connection is of course proportionately stronger. Webb says[1]: "A little *n p μ* Sagittarii, xviih. 57m., S. 18° 50′, is a spot referred to by Secchi as exemplifying in a high degree the marvellous structure which the great achromatic at Rome

[1] *Celestial Objects*, Fourth Edition, p. 385, footnote.

shows in the Galaxy. The remarks of this accomplished astronomer on the successive layers of stars are very curious : first he finds large stars and lucid clusters ; then a layer of smaller stars, certainly below 12 m. ; then a nebulous stratum with occasional openings. But what, he says, startled him, and all to whom he showed it, was the regular disposition

Fig. 11.—Streams of small stars in Telescopium and Corona Australis. From Behrmann.

of the larger stars in figures ' si géométriques qu'il est impossible de les croire accidentelles. La plus grande partie sont comme des arc de spirale ; on peut compter jusqu'à 10 ou 12 étoiles de la 9me à la 10me grandeur, . . . se suivant sur une même courbe comme les grains de chapelet ; quelquefois elles forment des rayons qui semblent diverger

d'un centre commun, et ce qui est bien singulier, on soit d'ordinaire que, soit au centre des rayons, soit au commencement de la branche de la courbe, on trouve une étoile plus grande et rouge. Il est impossible de croire que telle distribution soit accidentelle.'"

I have already noticed that on the Paris stellar photographs many cases may be found of three or more stars placed in a straight line, or nearly so. Sometimes a comparatively bright star seems to draw a train of fainter stars after it, and occasionally a stream of stars of nearly equal brightness may be traced for some distance from their source.

In the photograph of the cluster 38 Messier (see Plate XII.) this tendency to stream formation is well marked among the brighter stars. Webb describes it as "a noble cluster arranged as an oblique cross";[1] and Smyth says, "The very unusual shape of this cluster recalls the sagacity of Sir William Herschel's speculations upon the subject, and very much favours the idea of an attractive power lodged in the brightest part. For although the form is not globular, it is plainly to be seen that there is a tendency towards sphericity, by the swell of the dimensions as they draw near the most luminous place, denoting, as it were, a stream, or tide of stars, setting towards a centre."[2]

The stream tendency is also shown in the photograph of 35 Messier. Smyth says: "It presents a gorgeous field of stars from the 9th to the 16th magnitude, but with the centre of the mass less rich than the rest [evidently so on the photograph—J.E.G.]. From the small stars being

[1] *Celestial Objects*, Fourth Edition, p. 241.
[2] *Bedford Catalogue*, Original Edition, p. 123.

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inclined to form curves of three or four, and often with a large one at the root of the curve, it somewhat reminds one of the bursting of a sky rocket."[1] With reference to the cluster surrounding the star 12 Monocerotis Smyth says: "This is a brilliant gathering of large and small stars from the 7th to the 14th magnitude, the latter running in rays";[2] and he describes the cluster 36 Messier in Auriga as "a rich though open splash of stars from the 8th to the 14th magnitudes, with numerous outlines, like the device of a star whose rays are formed of small stars."[3] He speaks of the cluster H. vi. 30 in Cassiopeia (between ρ and σ) as "having spangly rays of stars which give it a remote resemblance to a crab, the claws reaching the confines of the space in view, under an eyepiece magnifying 185 times."[4]

Observing with a 3-inch telescope in India in July 1874, I noticed a beautiful cluster of stars about 4° north of λ and υ Scorpii, resembling in shape a bird's foot, with remarkable streams of stars. This cluster is visible to the naked eye as a star of 5 or $5\frac{1}{2}$ magnitude.

Sir William Herschel, speaking of the compressed cluster H. vi. 25 in Perseus, says "the large stars are arranged in lines like interwoven letters"; and Webb says "it is beautifully bordered by a brighter foreshortened pentagon."

In his "Catalogue of Nebulæ and Clusters" in the *Cape Observations*, Sir John Herschel has the following remarks:

No. 2754. "A pretty large, rich 6th-class cluster; irregular figure; in radiating streaks."

[1] *Bedford Catalogue*, Original Edition, p. 144. See Plate in *The Scenery of the Heavens*, p. 213.

[2] *The Bedford Catalogue*, p. 152.

[3] *Ibid.*, p. 129.

[4] *Ibid.*, p. 539.

No. 3080 (viii. 35). "The most compressed part of a great scattered cluster or rather region, more crowded with stars than the rest of the Milky Way, though hardly entitled to rank as a cluster. The stars are in singular lines and curves on a dark ground."

No. 3504 (ω Centauri). "All clearly resolved into stars of two magnitudes, viz., 13 and 15, the larger lying in lines and ridges over the smaller; . . . the larger stars form rings like lace-work over it."

No. 3778 (Dunlop 295). "The stars are of two magnitudes, the larger, 11 m., run out in lines like crooked radii. The smaller, 16 m., are massed together in and around the middle."

From the close proximity of the component stars—of some at least of these clusters—the reality of a physical connection between them seems beyond dispute; and from analogy we may conclude, I think, that "streams" and "sprays" of stars in other portions of the heavens are in some cases at least due to a real, and not merely an apparent, connection.

Professor Holden, speaking of a telescopic examination of the Milky Way, says: "Occasionally a double star will pass through the field of view, and the mind at once seizes on this; for here is a definiteness and order which gives a sense of relief from the chaos of stars among which it chances to fall.

"Small nebulæ have the same effect. We have certain definite notions about them also. If the eyepiece is changed to one which gives twice or thrice the field of view, and if the observer has acquired the skill to see with this power nearly all that is shown with the higher power,

then the sense of order which the mind instinctively seeks for can often be found in the arrangement of the stars themselves. Half-a-dozen stars in a row pass by with only a moment's attention in the smaller field, but when we see the first six stars succeeded by a stream of six, ten, or twenty more, the attention becomes riveted on this feature, and there is a positive sense of pleasure in tracing such a stream to its end.

"Some fields and regions are characterised by streams like this. Others are rich in small definite ellipses of stars, often all of the same size. In some cases stars are surrounded by circles of other fainter stars. In other instances the ellipses become tolerably regular ovals, often of a large size. These interlace in the most intricate manner. After having discovered such ovals as these we can frequently trace new and highly interesting features of the kind by paying attention to stars of one magnitude only.

"If we regard the 11th-magnitude stars alone, for example, we may find rings and ovals of these stars forming a regular pattern in the sky. Interlacing with these may be found another pattern of similar ovals (usually smaller) of stars of the 12th magnitude, and so on. In certain parts of the sky the arrangement is so intricate that no single pattern can be discovered. In most regions a little attention will show that there are several patterns, one for each of the fainter magnitudes of stars."[1]

On some photographs of the Milky Way taken by Mr. Barnard with a 6-inch portrait lens at the Lick Observatory, Professor Holden finds similar features.

In a paper in the *Monthly Notices*, R.A.S., April 1890,

[1] *Monthly Notices*, R.A.S., Vol. I., No. 2, December 1889.

Mr. Backhouse calls attention to the "straight lines and parallel arrangements of pairs, lines, and bands of stars, and also of irresolvable wisps" observed by him in the portion of the Milky Way included between the stars 15, 13, 8 Monocerotis, α Orionis, ζ Tauri, and 5, μ, ξ Geminorum; and "besides the parallelisms" he notes "a most wonderful case of *radiation of stars and wisps* in a fan-shaped group, 68 Orionis being approximately the centre."

Most of the observations were made with a binocular field-glass of 2·05 inches aperture, but some with a 4½-inch refractor. He finds a preponderance of the groupings "at an average deviation of 15° from the direction of Gould's Galactic Equator, viz., at a position angle of 345° with that great circle, and more nearly parallel with a Galactic Equator derived from Proctor's chart of the *Durchmusterung* stars"; and he adds: "One conclusion derived from the investigation is that the stars and wisps in parallel lines are probably in the same region of space; and therefore that the majority of the stars—at least, of those down to the 9th or 10th magnitude—in extensive tracts of the area examined are really near one another."

An examination of Dr. Boeddicker's beautiful drawing of the Milky Way seems to show that the Galaxy itself is—at least chiefly—composed of "star streams" and "star sprays," and clustering groups of small stars, and does not represent a "cloven" flat disc as was originally supposed.

Mr. Proctor pointed out that "the nebular system also shows the most marked tendency to stream formation." In the great nebular region in Virgo and Coma Berenices, he finds that "the stars are not arranged uniformly over either region, but to some degree clusteringly, with inter-

spersed spaces relatively vacant. Now no nebulæ appear in the more vacant spaces, nor do nebulæ appear chiefly where the stars are more clustered. It is on the borders of star clusterings and in the breaks of star streams that the nebulæ show themselves, precisely as though they had taken the place of stars where star matter began to fail." This seems very remarkable and suggestive.

CHAPTER XI.

STELLAR DISTANCES AND MOTIONS.

"How distant some of these nocturnal Suns!
So distant (says the Sage), 'twere not absurd
To doubt, if Beams, set out at *Nature's* Birth,
Are yet arrived at this so foreign World;
Tho' nothing half so rapid as their Flight."[1]

YOUNG.

THE determination of the distance of the stars from the earth has always formed a subject of great interest to astronomers. It is evident that a knowledge of the relative distances of bright and faint stars is of the highest importance in the study of sidereal astronomy. Could we accurately find the distance of every star, and also the distances of the brighter and fainter portions of the Milky Way, the problem of the construction of the stellar heavens would be immediately solved. We are, however, as yet very far from the attainment of such knowledge, the distances of only a few stars having been hitherto ascertained with any approach to accuracy.

The earlier astronomers seem to have considered the problem of stellar distance as an insoluble one. Tycho

[1] *Night Thoughts*, Night 9, The Consolation.

Brahé showed that—for his instruments at least—the stars had no sensible parallax. Kepler, judging from what he termed the "harmony of relations," concluded that the distance of the fixed stars should be about 2000 times the distance of Saturn from the Sun. The distance of the *nearest* star—as now known—is about 14 times greater than that deduced by Kepler. Huygens thought the determination of stellar distance by astronomical observations to be impossible, but made an attempt at a solution of the problem by a photometric comparison between Sirius and the Sun. By this method he found a distance for Sirius equal to 28,000 times the Sun's distance from the earth. Modern measures show this estimate to be far too small. The distance of Sirius from the earth is probably over 500,000 times the Sun's distance, or about 18 times greater than Huygens made it.

From similar photometric comparisons, the Rev. John Michell, in 1767, concluded that the parallax of Sirius is less than a second of arc, a result fully confirmed by modern researches.[1] He found that stars of the sixth magnitude are probably 20 to 30 times the distance of Sirius, and, judging from the relative brilliancy alone, this result would also be nearly correct.

It was during the course of a series of observations of double stars made by Sir William Herschel at the close of the eighteenth century with a view to determine their distance from the earth that he made his famous discovery of binary or revolving double stars. In these interesting systems the components are at practically the same distance

[1] Piazzi found a parallax of 4 seconds for Sirius, but this is now known to be certainly erroneous.

from the eye. In an "optical double," however, one of the components may be much more distant than the other. In this case measures of their relative positions at intervals during the year would enable us to determine the distance —or rather the relative distance—of the nearer component.[1] Owing to the imperfection of micrometers in Herschel's time, his efforts in this direction were unsuccessful, although his labours were amply rewarded by his splendid discovery of binary systems.

The "parallax" of a fixed star is the apparent displacement in its position on the celestial vault due to the earth's change of place in revolving round the Sun. The earth's orbital motion gives us a "base line" of about 186 millions of miles (the diameter of the earth's orbit). *Half* the total displacement observed, measured in seconds of arc, is the star's parallax. Even with this enormously long base line the observed parallax is in all cases very small. For the nearest of the stars—*a* Centauri—the most recently determined parallax amounts to only 0·″676 (Elkin), or 0·″76 (Gill).

From the parallax the stars' distance in miles may be found by simply multiplying the Sun's distance from the earth (about 93 millions of miles) by 206,265, and dividing the result by the observed parallax. To ascertain the time that light would take to reach us from the star—the "light journey," as it is called—it is only necessary to divide the number 3·258 by the parallax. Thus for *a* Centauri, taking the parallax at 0·″76, we have 3·258 divided by 0·76, equal to 4·28 years of light travel.

Among other stars which recent measures show to have

[1] See *Planetary and Stellar Studies*, p. 120.

a comparatively large parallax, the following may be mentioned[1] :—

61 Cygni. 0·″430, Glasenapp (absolute); 0·″432, Pritchard (relative); 0·433, Schweizer-Socoloff (relative); 0·″465 and 0·″468 (relative), Sir Robert S. Ball; and 0·″566, Auwers (relative), values in fairly close agreement.

Lalande 21,185. 0·″434, Kapteyn; 0·″501 and 0·″511, Winnecke (all relative).

Sirius. 0·″407, Elkin; 0·″370, Gill (both relative).

η Herculis. 0·″40, Belopolsky-Wagner (absolute).

η Cassiopeiæ. 0·″3743, Schweizer-Socoloff (relative).

Struve 2398. 0·″353, Lamp (relative).

34 Groombridge. 0·″307, Auwers (absolute).

α Canis Minoris (Procyon). 0·″266, Elkin; 0·″299, Wagner (both relative).

σ Draconis. 0·″262, and 0·″222, Brünnow (both relative).

40 (o^2) Eridani. 0·″166, Gill; 0·″233, Hall (both relative).

70 Ophiuchi. 0·″162 and 0·″169, Krueger (both relative).

Bradley 3077. 0·″205, Backluud-Wagner (absolute); 0·″283, Gyldén (relative).

A.-Oe. 17,415. 0·″1914, Schweizer-Socoloff (relative); 0·″247, Krueger (relative).

Among stars with small or insensible parallaxes may be mentioned:—

α Cassiopeiæ, for which Pritchard finds a relative parallax of 0·″036.

[1] See a valuable paper on this subject by Herbert Sadler, F.R.A.S., in *Knowledge* for February 1890, and *The Sidereal Messenger* for October 1890. A "relative" parallax denotes the parallax with reference to a small neighbouring star.

α Orionis, for which Elkin found a relative *negative*[1] parallax of 0·″009.

Lalande 20,670. A negative parallax of 0·″006 was found by Kapteyn.

β Ursæ Majoris. Klinkerfues found a positive parallax of 0·″0102 to 0·″0114.

γ Ursæ Majoris. Klinkerfues found 0·″0164 to 0·″0183.

ϵ Ursæ Majoris. Klinkerfues found 0·″0301.

A relative parallax of only 0·″018 was found for the brilliant Arcturus by Elkin;[2] and 0·″034 for Vega.

For α Cygni, another bright star, Elkin finds a negative parallax of 0·″042, and Glasenapp 0·″059; but as these are *absolute* measures there must be some error in the results. They would imply, however, that the parallax of α Cygni is insensible.

For α Cephei Pritchard finds a relative positive parallax of 0·″061.

Much smaller parallaxes than those just quoted would not of course be measurable. They would vanish among the errors of observation incidental to the best observers and the most perfect instruments. The accuracy of even the larger parallaxes given above cannot be considered as absolutely certain, the measurement of such small quantities being a matter of great difficulty and much uncertainty. Enough, however, has been done to show with considerable certainty that, among those hitherto measured at least, there is no star with a parallax so

[1] A negative parallax (if not due to errors of observation) may imply that the faint comparison star is actually nearer to the earth than the bright star of which the parallax was sought.

[2] Glasenapp, however, found an *absolute* parallax of 0·″210.

large as a single second of arc; or, in other words, that no star exists within a distance equal to 206,265 times the Sun's distance from the earth. Indeed, Professor Gyldén finds, from a discussion of the observed parallaxes and "proper motions" of 11 stars, a mean parallax for stars of the first magnitude of only 0·″083. This agrees fairly well with the result 0·″102 found by Professor C. A. F. Peters from Struve's observations at Dorpat, and better still with the value 0·″089 recently found by Dr. Elkin.[1]

An examination of the parallaxes quoted above will show that the brightness of a star is no test of its distance, bright stars like Arcturus, Vega, and *a* Cygni being actually farther from the earth than comparatively faint stars like 61 Cygni and Lalande 21,185. A real difference in size or intrinsic brightness must therefore exist among the stellar hosts, and this forms another argument against the so-called "disc theory" of our universe, in which the stars are supposed to be nearly uniform in size and brightness.

It is, however, probably true that if we take a large number of stars we should find that, on the average, the brighter stars are nearer to the earth than the fainter, even among those visible to the naked eye only. For example, could we accurately measure the distances of say a hundred stars brighter than the third magnitude and also a hundred stars between the fifth and sixth magnitudes, the *average* distance of the brighter set would probably be less than that of the fainter. This also applies, in all probability, to the faint stars which are only visible in large telescopes. For instance, we may conclude, I think, with considerable

[1] *Sidereal Messenger*, November 1888.

certainty that (so-called) sixteenth-magnitude stars lie, on an average, at a greater distance from the earth than stars of the sixth magnitude. The faintness of many of these small stars may, however, possibly be due more to smallness of size than the immensity of distance.

To show at what an enormous distance the fainter stars must be placed if really of average stellar size and brilliancy, I have drawn the accompanying diagrams (Plate XIII.). I have assumed a "light ratio" of 2·512—the value now generally adopted by astronomers—which denotes that a star of the first magnitude is 2·512 times as bright as a star of the second magnitude, a star of the second magnitude 2·512 times brighter than one of the third, and so on. As this is a geometrical progression, the light of the smaller stars decreases very rapidly. Thus a star of the first magnitude is 100 times as bright as one of the sixth, and a sixth-magnitude star 10,000 times brighter than one of the sixteenth. Hence a first-magnitude star would be equal in brightness to 1,000,000 stars of the sixteenth magnitude.

Now as light varies inversely as the square of the distance, we have—assuming that there is no loss of light in transmission—the distance of a sixth-magnitude star equal to 10 times that of a first magnitude, and the distance of a sixteenth magnitude equal to 1000 times that of a first magnitude, or a 100 times that of a sixth. The distances corresponding to the intermediate magnitudes are easily computed, and a table of these distances will be found in the Appendix (Note H).

These distances are shown graphically in the diagrams (Plate XIII.). As a single diagram would be incon-

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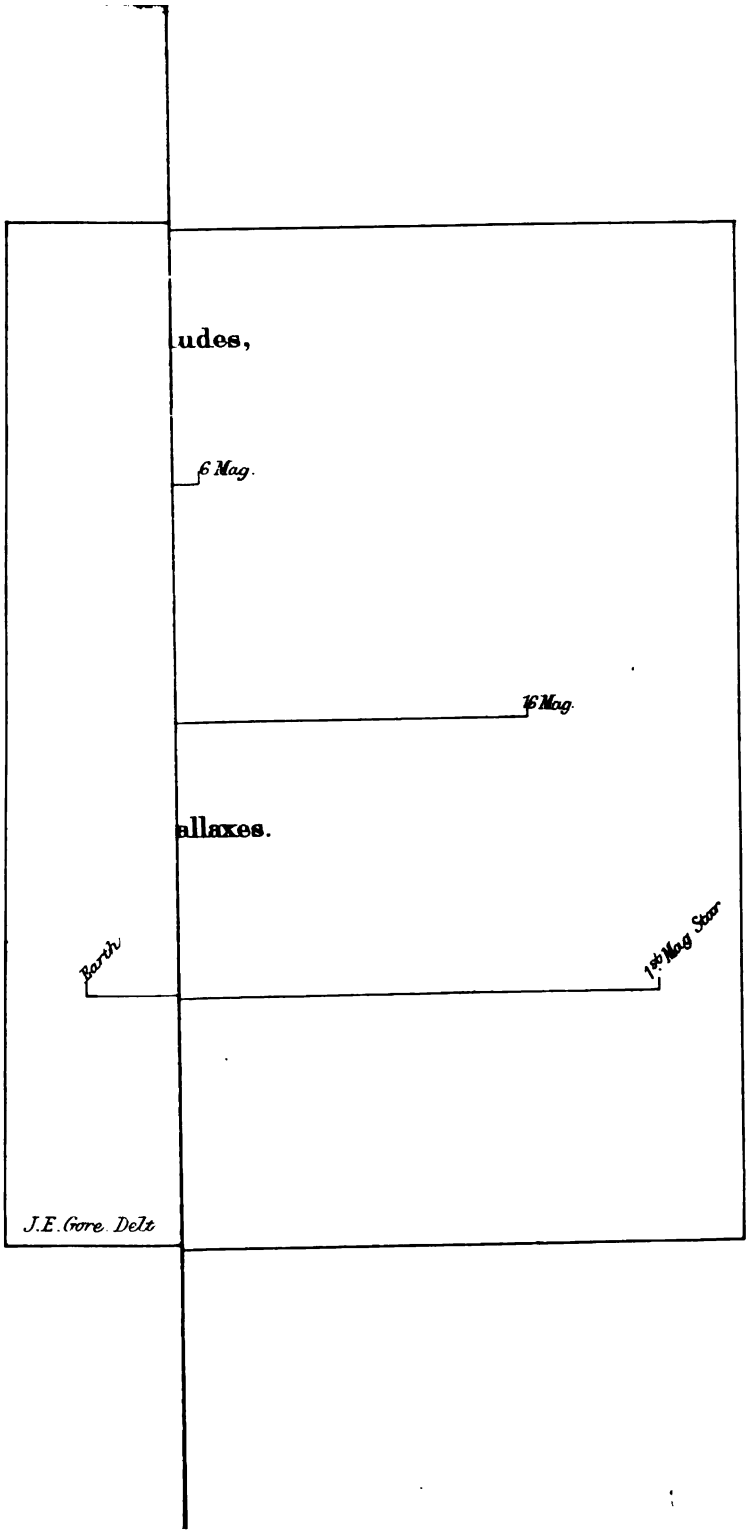
udes,
6 Mag.
16 Mag.
allaxes.
Earth
1st Mag. Star
J.E. Gore. Delt.

veniently long if drawn to the same scale, I have drawn two figures, one (Fig. 1) for stars down to the sixth magnitude, in which the unit is the distance of stars of the first magnitude, and the second (Fig. 2) for stars to the sixteenth magnitude, in which the unit is the distance of stars of the sixth magnitude.

Dr. Elkin's mean parallax of 0·″089 for stars of the first magnitude would give a light journey of 36·6 years. For sixth-magnitude stars the light journey would therefore be 366 years, and for stars of the sixteenth magnitude no less than 36,600 years!

Another diagram (Fig. 3) shows the relative distances of some of the stars for which a parallax has been found. It will be seen that all these distances are less than the average distance of stars of the first magnitude. These stars must therefore be considered as comparatively near neighbours of the Sun.

When we come to the nebulæ the difficulty of determining their distance is increased by the fact that—at least, in the case of the gaseous nebulæ—they contain no definite point of light, like a star, from which measures can be made. In the case of the clusters the components are probably at nearly the same distance from the earth, and therefore comparison stars are not available.

Bredechin found for Herschel's nebula IV., 37 (G. C. 4373) a parallax of 0·″009, and Brünnow 0·″047 (both relative); but the accuracy of these results seems doubtful.

The fact that the stars are not absolutely "fixed," but that some of them, at least, have a "proper motion" across the face of the sky, seems to have been first detected by Halley. He found from his own observations in 1715 that

the bright stars Sirius, Arcturus, and Aldebaran had sensibly shifted their apparent position since the date of the earliest observations. This interesting result was confirmed in 1738 by James Cassini, who found that Arcturus had moved through about five minutes of arc in 152 years, or about two seconds per annum, agreeing fairly well with the modern determination of 2″·3 annually.

Modern observations have fully confirmed the discovery of stellar movements, and a considerable number of stars are now known having perceptible motions. I give in the Appendix (Note I) a list of "proper motions" greater than two seconds of arc per annum, for which I am indebted to Miss Clerke's most interesting and valuable work *The System of the Stars*. From this it will be seen that the largest proper motion yet detected is that of the small star 1830 of Groombridge's Catalogue, which has an annual motion of seven seconds, a motion which would carry it through a space equal to the Moon's apparent diameter in about 266 years.

It will be seen from the table that the four stars with motions greater than five seconds annually are below the fifth magnitude, and that of eight stars with motions greater than four seconds none are brighter than the fourth magnitude.

Of the 24 stars with proper motions exceeding two seconds there are only two (*α* Centauri and Arcturus) whose magnitude exceeds the third. As a large proper motion is considered as a test of proximity to the earth, this result is very significant, a significance accentuated by the fact that about half the number have yielded a measurable parallax.

Of stars with a proper motion of less than two seconds, but greater than one second per annum, the following are brighter than the fourth magnitude: Sirius (1·″3), Procyon (1·″3), γ Serpentis (1·″3), η Cassiopeiæ (1·″2), and θ Ursæ Majoris (1·″1); and there are some ten stars fainter than the eighth magnitude. Indeed, more than one half the number of stars with motions greater than one second are below the limit of naked-eye vision.

There are a large number of stars with proper motions of less than one second per annum, and further researches may perhaps show that no really "fixed" star exists in the heavens.

M. Ludwig Struve found for stars of the sixth magnitude an average proper motion of eight seconds per century. As the mean distance of stars of this brightness should be—on the assumption of uniform size and brightness—ten times that of a first-magnitude star, we should find the mean proper motion of first-magnitude stars to be eighty seconds in a hundred years. The twenty brightest stars, however, show an average motion of only sixty seconds in the same time. Stars of the second magnitude show a still slower motion. Instead of fifty seconds per century due to their hypothetical distance, 22 stars of this magnitude have yielded a mean motion of only seventeen seconds.

When the distance of a star from the earth is known and its "proper motion" has been ascertained, it is easy to calculate its absolute velocity in miles per second in a direction at right angles to the line of sight. We have simply to multiply the proper motion in seconds of arc by 2·943, and divide by the measured parallax, also expressed in seconds of arc. In the Appendix (Note J) will be

found a table in which I have computed the velocities for some of the fastest moving stars, and also the number of years taken by light in reaching us from the star in question. This is obtained by dividing 3·258 [1] by the parallax, as already stated.

There are some cases in which stars at a considerable distance apart are moving through space with a common proper motion. For instance, 17 Cygni and Struve 2576, fifteen minutes of arc apart, are moving in company slowly towards the south ; 36 Ophiuchi and 30 Scorpii, at a distance of more than twelve minutes, have a common proper motion of 1·″22 per annum ; and there are some faint stars near the pair which participate in their motion. Two stars in Libra (A.-Oe. 14,318 and 14,320), distant five minutes of arc, are moving together at the rapid rate of 3·″6 per annum.

Mr. Proctor's discovery of common proper motion in five out of the seven stars in the "Plough" has not been fully confirmed by Professor Auwer's subsequent investigations. The stars ϵ and ζ are, however, apparently moving in the same direction, and we have still a quintuple system in ϵ, ζ Alcor, and the telescopic and spectroscopic companions of ζ.

From an examination of stellar "proper motions," astronomers have come to the conclusion that the Sun and Solar System are speeding through space with a considerable velocity. The fairly accordant results obtained by different computers leave no doubt of the reality of this motion. The first investigation on the subject was made

[1] Corresponding to a solar parallax of 8·″80 and a velocity of light of 186,300 miles a second.

by Sir William Herschel, who found, in 1783, that the Sun is moving towards a point near λ Herculis, a result which differs but little from modern determinations. The investigations of MM. Argelander, Peters, and O. Struve led to the following result—as stated by M. O. Struve in his *Études d'Astronomie Stellaire*, p. 108 :—

"Le mouvement du système solaire, dans l'espace est dirigé vers un point de la voûte céleste, situé sur la ligne droite qui joint les deux étoiles, de troisième grandeur, π et μ Herculis, à un quart de la distance apparente de ces étoiles, a partir de π Herculis. La vitesse de ce mouvement est telle, que le Soleil, avec tous les corps qui en dépendant avance annuellement, dans la direction indiquée, de 1·623 [1] fois le rayon de l'orbite terrestre, ou de 33,550,000 milles géographiques. L'erreur probable de ce dernier chiffre s'élève à 4,733,000 milles géogr. ou à un septième de la valeur trouvée. On peut donc parier 40,000 contre un, pour la realité du mouvement propre progressif du Soleil, et 1 contre 1 qu'il est compris entre les limites de 38 et de 29 millions de milles géographiques."

Recent researches have fully confirmed the general accuracy of this conclusion, at least so far as the *direction* of the motion is concerned. The following are some of the most accordant results hitherto obtained [2] :—

	R. A.	Decl.
Sir W. Herschel	260·6	+ 26·3
Gauss	259·2	+ 30·8
Argelander	259·9	+ 32·5
O. Struve	261·5	+ 37·6
Galloway	260·1	+ 34·6
Airy	261·5	+ 24·7

[1] This corresponds to a parallax of 0″·209 for stars of the first magnitude. As this value is probably too large, the resulting velocity of the solar motion is probably too small.

[2] *The Observatory*, April 1888 and January 1891.

	R. A.	Decl.
Dunkin	263·7	+ 25·0
L. de Ball	269·0	+ 23·2
Rancken	284·6	+ 31·9
Ubaghs	262·4	+ 26·6
L. Struve	273·3	+ 27·3
O. Stumpe	287·9	+ 31·9
„	285·2	+ 30·4

From a combination of his own result with 15 others, L. Struve finds R. A. 266·7°, Decl. + 31, which places the "solar apex," as it is called, a little *north preceding* the 4½-magnitude star ν Herculis. The diagram (Plate XIV.) shows the above positions with reference to stars in Hercules and Lyra.

The amount of the solar motion has not been well determined, but L. Struve finds the value 4·″36 in 100 years as seen from the average distance of a sixth-magnitude star. If we take the parallax of a sixth-magnitude star at 0·″009,[1] this gives the actual velocity of the solar motion about 14¼ miles a second. Too much reliance should not, however, be placed on this value, as other astronomers have found different results.[2]

The whole of the stellar motions cannot, however, be explained by the Sun's motion. Most of the so-called "fixed stars" have doubtless, like the Sun, motions of their own in different directions through space. The observed "proper motion" is in many cases real and not merely apparent. For instance, the direction and velocity of motion of the "runaway star" 1830 Groombridge cannot

[1] Or $\frac{1}{10}$th of the parallax of a first magnitude assumed to be 0·″089.

[2] *Monthly Notices*, R. A. S., Vol. XLIX., No. 4, p. 221.

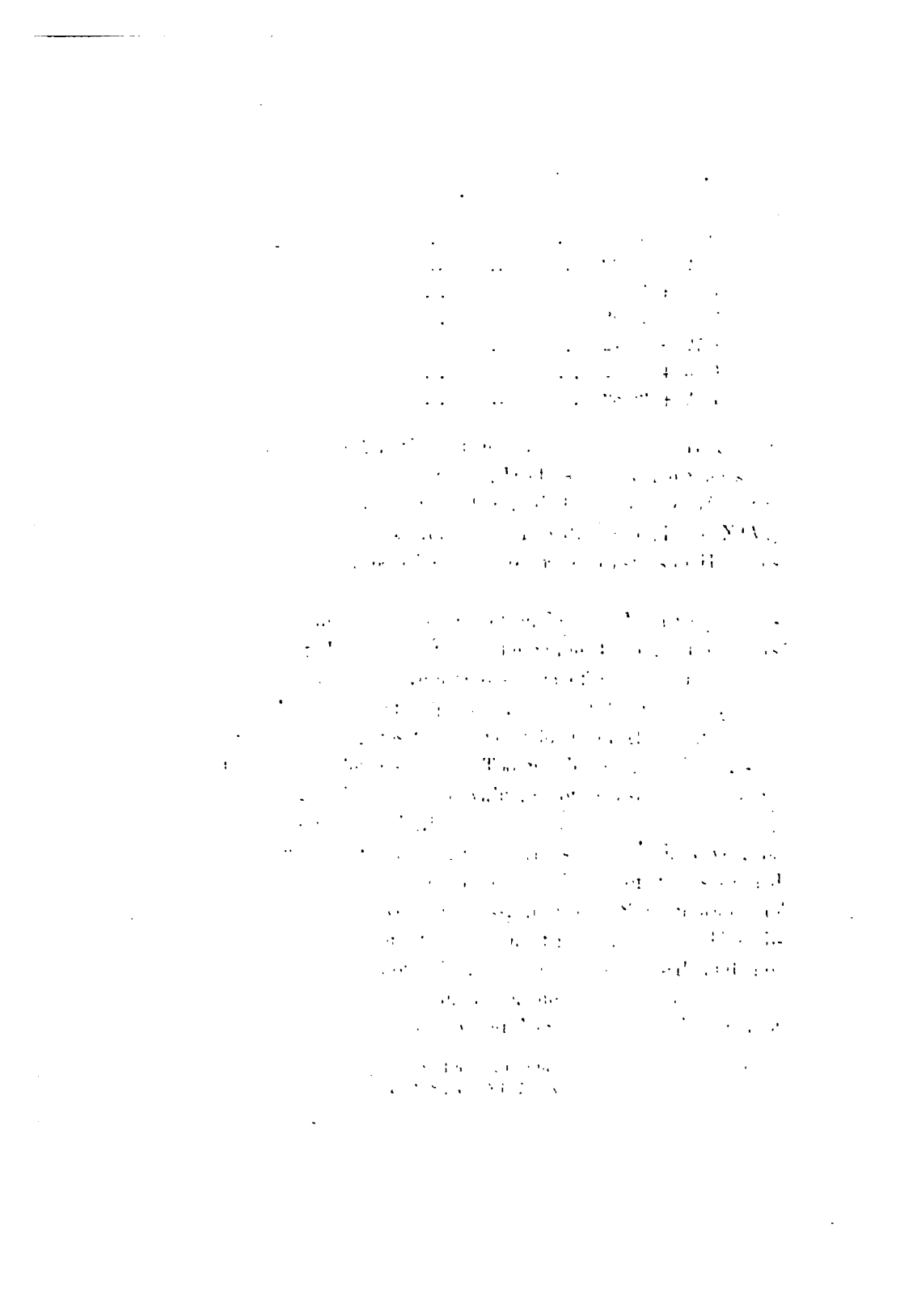

PLATE XIV.
Positions of the "Solar Apex,"
According to different computers.

be explained solely by the Sun's motion, and there are many somewhat similar cases.

Professor Newcomb finds for the Pleiades cluster a proper motion of 5·″8 per century. If we assume that this apparent motion is wholly due to the Sun's real motion through space at the rate of, say 14 miles a second, the parallax of the Pleiades would be only 0·″0122 corresponding to a light journey of about 267 years. We cannot be certain, however, that the Pleiades are absolutely at rest, and that their apparent motion is due solely to the Sun's motion. The group may possibly be travelling in the same direction as the Solar System, and this would have the effect of diminishing its apparent proper motion. A cluster so large and bright as the Pleiades certainly does not suggest great distance from the earth.

In addition to the transverse motion across the face of the sky many stars have also a motion in the line of sight, either towards or away from the earth. These motions have only been detected in recent years by the aid of the spectroscope. Dr. Huggins was the first to show that such motions could be determined by measuring the displacement of the spectral lines caused by the approach or recession of the source of light, the lines being slightly shifted towards the blue end of the spectrum when the star is approaching the earth, and towards the red end when it is receding from us.[1] From the amount of the observed displacement, the velocity in the line of sight can be easily computed (see Appendix, Note K).

Some of the earlier measures of motion in the line of

[1] The effect would of course be the same if the *star* were at rest and the earth in motion.

sight were very discordant, but measures of the photographed spectra have recently given much better results.

The following stars, among others, show a *certain* motion of approach: Arcturus, Vega, Procyon, Pollux, Altair, Spica, α Cygni, α Cephei, α Persei, α Arietis, β Leonis, and the Pole Star; and the following show a well-marked motion of recession: Capella, Rigel, α Orionis, Aldebaran, Regulus, and ϵ Orionis.

Professor Vogel's measures from photographs of stellar spectra have yielded much more accurate results than those made by eye measurement at the telescope. By the new method Vogel finds a velocity of recession of 39 miles a second in Rigel, 30 miles in Aldebaran, 35 in ϵ Orionis, and 15 in Capella; and a velocity of approach of 16 miles per second in the Pole Star and 7 miles in Procyon.

Any motion in the line of sight will of course increase the velocity deduced from the star's "proper motion" and parallax, so that the velocity of a star computed from its proper motion alone must, unless it be moving at right angles to the visual ray, be considered as the *minimum* value.

A consideration of the Sun's motion in space has suggested to the present writer an interesting question. What was the position of the Sun, and with it the Solar System, during the past geological ages of the earth's history? To obtain an accurate reply to this question it would of course be necessary to know the exact nature of the path the Sun is pursuing. Such knowledge is, however, not yet available. We do not know whether it is moving in a straight line or describing some vast orbit in space. And ages may, and probably must, elapse before this point

is decided. Let us assume, however, that the motion is rectilinear and uniform, and the velocity about 14 miles a second. From L. Struve's position of the "solar apex," or the point towards which the Sun is moving, R. A. 266°·7, Decl. + 31°, the "ant-apex," or point *from* which the Sun is moving, lies in R. A. 86°·7, Decl. −31°, or in the southern constellation Columba, not very far from Sirius. Now, with a parallax of 0″·39, the distance of Sirius from the earth would be about 49 billions of miles. With a velocity of 14 miles a second the Sun's annual motion would be nearly 442 millions of miles. Therefore in 200,000 years the distance traversed would be about 88 billions of miles, which carried back would place it out in space far beyond the distance of Sirius. If we go back, say 10 millions of years, we find the Sun at the vast distance of 4420 billions of miles, or about 90 times the present distance of Sirius, a distance corresponding to a parallax of only 0″·0043. At this immense distance the light of Sirius would be reduced to a star of about magnitude 8¾. Hence it follows that if there are any stars of about this brightness close to the "ant-apex," and of about the same real size and brilliancy as Sirius, the Sun, if moving in a straight line, must have been close to the *present* position of these stars some ten millions of years ago.

With reference to a possible motion of the stars in some general system, M. Rancken has found[1]—from an examination of 106 stars—a tendency to drift along the course of the Milky Way from Aquila towards Cygnus and Cassiopeia and past Capella through Orion to Argo. The *larger* motions shown in Proctor's map of "proper

[1] See Miss Clerke's *System of the Stars.*

motions" exhibit this tendency in a marked degree between *a* Cygni and Capella, and less clearly on to Sirius, but the smaller motions not so well.

If the "solar cluster" referred to in the chapter on the Milky Way is moving as a whole in the same direction as the Sun, or revolving round a common centre of gravity, the proper motions of the component stars would be in the same direction, and might therefore be masked by the motion of the Sun itself. It would be difficult then to determine whether such a motion really exists, and the realisation of such a result is attended with great difficulties. These difficulties may, however, be overcome in the future, and the true relation of the Sun to its nearest neighbours may possibly be ascertained with some approach to accuracy. Miss Clerke rejects, however, the theory of a "solar cluster," or at least considers "that Gould's cluster is *not* organised on an independent dynamical footing."

The hypothesis of a central Sun round which the whole Sidereal System revolves, originally suggested by Wright of Durham in 1750, and supported by Mädler in recent years, has been rejected by astronomers as resting on an insufficient foundation.

Although "the stars in their courses" may not form subjects of a system owing allegiance to the autocratic sway of a central sun, still they may possibly be guided by some law as yet unknown, and the tangled skein of stellar motions may perhaps one day be successfully unravelled by a generation of astronomers yet unborn.

CHAPTER XII.

GIANT AND MINIATURE SUNS.

THE stars which "deck" our midnight sky shine with all degrees of brilliancy from that of Sirius, "the monarch of the skies," down to the faintest points of light visible in our largest telescopes. Photometric measures show that Sirius is about two magnitudes brighter than an average star of the first magnitude, such as Altair and Spica. The faintest stars visible in the great Lick telescope have been estimated to be of the seventeenth magnitude in the same scale. We have therefore a difference of eighteen magnitudes between the light of Sirius and that of the faintest stars which have yet been seen with the telescope. This, on the generally accepted light ratio of 2·512, implies that Sirius is about 15,840,000 times brighter than the faintest visible star. A cluster of these faint stars containing 15 millions would not therefore exceed Sirius in brilliancy!

At first sight it would seem to be a plausible hypothesis that the stars are in general of about equal size and brightness, and that their relative brilliancy depends upon their distance from the earth, the brightest being the nearest and the faintest the farthest from our eye. As light varies inversely as the square of the distance, stars of the seventeenth magnitude would lie, on this supposition, at

a distance from us equal to the square root of 15,850,000, or 3981 times the distance of Sirius.[1]

Measures of stellar distance do not, however, lend much support to this apparently reasonable hypothesis of equable distribution and size among the starry hosts. We now know that the brightest stars are not *always* the nearest. The most reliable measures indicate that Sirius, the brightest of all, is a little farther from us than 61 Cygni, a star of the fifth magnitude (and therefore 250 times fainter). Sirius is, however, within measurable distance; but Canopus, a southern star (not visible in England), second only to Sirius in brilliancy in the whole heavens, has a very small and scarcely perceptible "parallax." It must therefore be a globe of enormous size, or else its intrinsic brilliancy must be very intense.

The stars are therefore of very various sizes, some probably far larger than the Sun, others perhaps much smaller. Indeed, we have good reason to suppose that our own Sun is a relatively small one when compared with its neighbouring suns in stellar space. The mean parallax of stars of the first magnitude has been found by Dr. Elkin to be only 0·″089. Placed at the great distance indicated by this comparatively small parallax the Sun would shine only as a star of about $6\frac{1}{2}$ magnitude, so that its insignificance in size compared with the brightest of the stellar hosts is at once obvious.

[1] It should be stated, however, that some astronomers have supposed that possibly the brilliancy of the stars may suffer some diminution owing to the absorption of their light in the ether of space. If this were the case, the distance of the faintest stars would not be so great as computed above. The hypothesis of an extinction of light will not, however, interfere with the general theory of uniform size and distribution in space.

The brightest star in the Northern Hemisphere is perhaps Arcturus, although it is closely rivalled by Capella and Vega. For Arcturus Dr. Elkin has recently found the minute parallax of 0·″018. This is a "relative parallax," or the parallax with reference to the faint neighbouring stars. Taking the parallax of 0·″407 for Sirius, as found by Elkin, we have the distance of Arcturus from the earth 22·6 times that of Sirius. If therefore both stars were of the same size and intrinsic brilliancy, Sirius would be $(21{\cdot}6)^2$, 510·76 times as bright as Arcturus. This would imply a difference of 6·77 magnitudes between the two stars.

But, according to the Oxford photometric measures, Sirius is only 1·26 magnitude[1] above Arcturus, or about 3·19 times as bright. Arcturus must therefore—if the small parallax found for it be reliable—be either a considerably larger sun than Sirius, or else a body of much greater intrinsic brilliancy. The spectrum of Sirius is of the first type, and that of Arcturus of the second or solar type. Now there seems to be good reason for supposing that stars of the first or Sirian type are really hotter, and therefore probably more luminous, than those of the second type.

We cannot therefore consider Arcturus to be *intrinsically* brighter than Sirius, and must conclude that its great comparative brilliancy is due to its greater size. As its spectrum is very similar to that of the Sun (with slight differences, however), the two suns may perhaps be fairly comparable in intrinsic brightness.

Let us then make an attempt to compare their relative size. The small parallax found for Arcturus indicates a distance of about 11,000,000 times the Sun's distance from

[1] According to the Harvard measures the difference is 1·46 magnitude.

the earth. If therefore the Sun were placed at the distance of Arcturus, its light would be reduced by the square of 11,000,000, or

121,000,000,000,000 times.

Now Steinheil in 1836, using the light of the Moon as an intermediary, found the light of the Sun equal to

6,008,000,000 times the light of Arcturus.

G. P. Bond, however, in 1861 found for α Centauri, a southern star of about the same brightness as Arcturus, a result which made the Sun 19,490,000,000 times brighter than that star. These results are rather discordant, but for our present purpose it will perhaps be sufficient to take a mean of the two determinations. This gives the light of the Sun equal to

12,749,000,000 times the light of Arcturus.

Comparing this with the result found above for the diminished light of the Sun at the distance of Arcturus, we see that Arcturus is about 10,000 times brighter than it should be were it of the same size and brightness as our Sun. Assuming that the intrinsic brightness of both bodies is the same, and that the relatively greater brilliancy of Arcturus is due to its greater size, we have the diameter of Arcturus equal to the square root of 10,000, or 100 times the diameter of our Sun, and its volume equal to 1,000,000 times that of the Sun! This would give an actual diameter of no less than 86,600,000 miles—an astounding result! The small value of the parallax found for Arcturus of course renders its accuracy somewhat

doubtful; but there can be little doubt, I think, that Arcturus is a far larger body than our Sun.

Let us test the above method of calculation by the case of *a* Centauri, of which the parallax has been fairly well determined. Being a binary or revolving double star, its mass, or rather the sum of the masses, of the components can therefore be computed in terms of the Sun's mass without any reference to its brightness. This has been done with the result that the combined mass of this double star is about twice the mass of the Sun.

Now a parallax of 0·″76, found by Gill, implies a distance of 271,400 times the Sun's mean distance from the earth. The Sun, placed at the distance of *a* Centauri, would therefore be reduced in brightness by the square of 271,400, or 73,657,960,000 times. Dividing this by the result found by Bond for the light of *a* Centauri, we find that the star is about 3·78 times brighter than the Sun would be at the same distance. The combined light of the components would therefore be equivalent to that of a sphere with a diameter of about 1·94 times that of the Sun. This would give a volume about 7·3 times the Sun's volume, a result which is not very discordant compared with the mass found from the orbit, for we must remember that the densities may be different, and *a* Centauri may possibly be hotter, and therefore intrinsically brighter than the Sun.

Another star which may also be classed as a "giant sun" is *a* Cygni (Deneb). The most recent measures of this star have yielded no positive parallax. It is of course a considerably fainter star than Arcturus,—one magnitude less, according to the Oxford measures,—but still of sufficient brilliancy to entitle us to rank it, in view of its vast

distance, among the "giant suns" of our universe. It has a spectrum of the solar type.

Among other bright stars which may be considered as members of the "giant" class may be mentioned the following :—

Capella (*a* Aurigæ). For this bright star Dr. Elkin finds a parallax of about $\frac{1}{10}$th of a second. This is of course considerably greater than that found for Arcturus, indicating, in fact, that Capella is at only $\frac{2}{11}$ of the distance of Arcturus. As the spectra of both stars are of the second or solar type they are perhaps comparable in their physical character as well as in their apparent brilliancy. Now the square of $\frac{2}{11}$ is $\frac{4}{121}$, or about $\frac{1}{30}$, and therefore Capella should be, at its smaller distance, if of the same size, 30 times brighter than Arcturus. They are, however, nearly of the same brilliancy, and hence the diameter of Capella would be the square root of $\frac{1}{30}$, or $\frac{1}{5 \cdot 5}$ that of Arcturus. This would make the diameter of Capella $\frac{100}{5 \cdot 5}$, or about 18 times that of the Sun, equivalent to an actual diameter of $15\frac{1}{2}$ millions of miles—a sufficiently stupendous globe! If we compare the Sun directly with Capella, we arrive at a similar result. The spectra are almost identical, so we may assume them to have the same intrinsic brightness.

The Sun, placed at the distance of Capella, would shine as a star of only the sixth magnitude, which shows clearly that Capella must be a "giant sun."

Vega (*a* Lyræ). Dr. Elkin finds for this brilliant white star a parallax of 0·″034, or about double that of Arcturus. Vega should therefore be about four times brighter than Arcturus. They are, however, of nearly equal brilliancy. This result taken in connection with the fact that the

spectrum of Vega is of the first or Sirian type, while that of Arcturus is of the solar type, indicates that Arcturus is a considerably larger sun. The small parallax of Vega, however, combined with its great brilliancy, shows it to be a sun of large size.

For the bright star Rigel (β Orionis) Dr. Gill finds a small *negative* parallax, which implies that it is actually farther from the earth than the small comparison stars ($8\frac{1}{2}$ magnitude). It must therefore be a sun of enormous size or great brilliancy. It would also indicate that the comparison stars are *relatively* small bodies.

α Cephei (Alderamin). This is another distant star, although not so far off as Arcturus. By means of photography Professor Pritchard found a parallax of only 0·″061. This would place it about $\frac{1}{3 \cdot 38}$ of the distance of Arcturus. α Cephei should therefore be $(3 \cdot 38)^2$, or 11·42 times brighter than Arcturus. Now the Oxford photometric measures give a difference of about 2·26 magnitudes in the light of the two stars, indicating that Arcturus is apparently about 8 times brighter than α Cephei. We see therefore that Arcturus is relatively about 91 times (11·42 × 8) brighter than Alderamin—a further proof of the probably enormous size of Arcturus. The spectrum of α Cephei is of the first or Sirian type.

For Pollux (β Geminorum) Dr. Elkin finds a parallax about the same as that of α Cephei ; and as it is a brighter star, with a spectrum of the second or solar type, while that of α Cephei is of the Sirian type, Pollux is probably a larger sun than Alderamin, but of course not equal to Arcturus, which, as far as the available evidence goes, seems to be the largest of all.

For β Ursæ Minoris, a reddish star with a spectrum of the solar type, Brioschi found a negative parallax, suggesting an enormous distance and a sun of great size.

For the bright reddish and variable star α Orionis (Betelgeuse) Elkin found a very small negative parallax. As this is a *relative* parallax it may imply that the star is actually farther from us than the faint stars of comparison! Considering its brilliancy and the banded character of its spectrum, the star would seem to be a body of enormous size, probably rivalling Arcturus in magnitude.

Among the southern stars the brilliant Canopus (α Argûs) must, as I have said, rank as a "giant sun," possibly one of the largest in the heavens. It is second only to Sirius in brilliancy. Sir J. Herschel's photometric observations at the Cape of Good Hope give it about 2·748 times the light of Arcturus,[1] or a little over one magnitude. The Cordoba observations, however, make it only 0·4 magnitude, or 1·446 times brighter. Taking a mean of these results, we have the light of Canopus about twice that of Arcturus. Dr. Elkin found a parallax of 0·″03, which places it at $\frac{3}{5}$ of the distance of Arcturus. Its brightness should therefore be $(\frac{3}{5})^2$, or $\frac{5}{9}$, equal to 2·777 times that of Arcturus—if both stars were of equal size and intrinsic brilliancy. This result agrees closely with Sir John Herschel's estimate of their relative brightness, and would imply that Canopus is quite as large a sun as Arcturus. There is, however, a difference in their spectra, which denotes some difference in their physical constitution and intrinsic brightness. Comparing Canopus with Vega, for which Elkin finds nearly the same parallax, we see that Canopus is probably a larger

[1] *Cape Observations*, p. 367.

sun than α Lyræ. For the bright southern star β Centauri Dr. Gill found a negative parallax—a "relative" one—so that here probably we have another "giant sun."

With regard to Sirius itself, which, with reference to its great apparent brilliancy, has been termed "the monarch of the skies," the comparatively large parallax shown by recent measures indicates that in absolute size it is probably much smaller than many fainter stars. A parallax of 0·″39, combined with the elements of the orbit recently computed by the present writer, gives for the combined mass of the components only 3·114 times the mass of the Sun; so that, compared with some of the stars referred to above, Sirius can no longer be considered as a "giant sun." It would appear to be simply a star of great intrinsic brilliancy comparatively near our system. Professor Lockyer thinks it is one of the hottest stars in the heavens.

Among the variety of objects which constitute the sidereal system it seems highly probable that there are miniature as well as giant suns. In the Solar System we have giants like Jupiter and Saturn and "pocket planets" like some of the asteroids and the moons of Mars. Probably a similar diversity of size may exist among the suns of the great stellar system.

If we consider the Pleiades as forming a large cluster of roughly globular shape—as it most probably does—the distance from the earth would be practically the same for all the component stars. The great difference of magnitude between the constituents is therefore very suggestive. The brightest star of the group, Alcyone, is about the third magnitude. The faintest stars shown on the photographic

chart made at the Paris Observatory are called seventeenth magnitude. Here we have a difference of 14 magnitudes, which implies that Alcyone is no less than 398,107 times brighter than the faintest stars of the group. If of the same intrinsic brilliancy, the diameters would therefore be in the ratio of 631 to 1.

As the spectrum of Alcyone is of the first or Sirian type, it is probably a very hot and very bright star. It may not therefore be a very large one, although probably placed at a great distance from the earth. If, to fix the attention, we assume its diameter at say 631,000 miles, the diameter of the faintest stars of the cluster would be only 1000 miles.

It is of course highly improbable, if not impossible, that the intrinsic light and heat of so small a star would be equal to that of the larger one; but, allowing a large multiplier for the greater intrinsic brightness of Alcyone—a factor of 64 would make the smaller star only 8000 miles in diameter—it seems very probable that these faint stars, which lie near the limit of visibility—even for the photographic plate—are in reality miniature suns. If we take the diameter of Alcyone as 10 times greater than that assumed above, or 6,310,000 miles, the faintest stars in the Pleiades, by the above calculation, would be only 80,000 miles in diameter, or somewhat less than the planet Jupiter in volume.

In some cases of course, faintness of light may be really due to vastness of distance. It would be possible to place Sirius itself—at least in imagination—at such a distance that it would vanish from our view even in the great Lick telescope. But such cases would, I think, be comparatively

rare. As I have shown in another chapter, it seems improbable that the faint stars which produce the nebulous light of the Milky Way are really suns of average size and brightness reduced to faintness by enormous distance. The single fact of nebulous rays and wisps, admittedly formed of faint stars, apparently connected with much brighter stars, is sufficient evidence, I think, to show that large and small stars may co-exist in the same region of space. Further evidence in the same direction is afforded by the structure of the larger "Magellanic Cloud" in the Southern Hemisphere, in which stars of the seventh magnitude and much fainter ones are apparently mixed up with clusters and nebulæ in a space which is probably of a globular form. In this wonderful collection of sidereal objects there are several clusters somewhat similar to the globular cluster in Hercules (13 Messier), which may therefore not be farther from the earth than stars of the seventh magnitude.

Positive evidence we have, however, in some of the binary stars, the components of which, revolving round their common centre of gravity, are of course at practically the same distance from the earth. In the case of 85 Pegasi, the primary is of the sixth magnitude, and the companion of the eleventh, indicating that the brighter star shines with 100 times the light of the fainter. Combining the elements of the orbit found by Schaeberle with a small parallax found by Brünnow, I find the mass of the system about eleven times the mass of the Sun. If of the same intrinsic brilliancy, the diameters of the components would be as ten to one, and their masses therefore as 1000 to 1. This would imply that the mass of the companion is about $\frac{1}{91}$ of the mass of our

Sun. We have other cases in δ Cygni, magnitudes 3 and 8, and 99 Herculis, of which the components are about $5\frac{1}{2}$ and 11. These smaller components of binary stars may of course be also considered as large planets in the sun-like stage of their existence.

CHAPTER XIII.

ON SOME EARLIER THEORIES OF THE UNIVERSE.

IF we consider that in viewing the starry heavens we are placed at the centre of a hollow sphere of vast and indefinite extent, and that the distance of only a few of the stars from our eye has hitherto been ascertained with any approach to accuracy, the great difficulty of framing a satisfactory theory of the construction of the heavens will be easily understood. Although Jupiter's system of satellites forms a most perfect piece of celestial mechanism, a mere glance through a telescope might lead us to suppose that absence of symmetry was its most striking characteristic. The cause of this imperfect view is clearly the unfavourable situation of our standpoint.

The case may be similar with the sidereal system, and could we examine it from a conveniently situated position, we might perhaps find, instead of apparent irregularity, an harmonious arrangement of all its parts, somewhat similar perhaps, but more complicated, to the planetary system, as seen from the Sun, or from a point at right angles to its general plane.

Before proceeding to discuss the celebrated researches and theories of Sir W. Herschel on the constitution of the Milky Way and the visible heavens, it may be interesting

to give a short account of the opinions advanced by some of his predecessors in the same field of research. Some of these earlier views, although very vague and visionary, seem to have contained the germs of subsequent theories, or more probably suggested ideas which were afterwards embodied in more plausible hypotheses.

The famous Kepler, whose laws of planetary motion have made his name for ever immortal, was born in 1571 in the town of Weildiestadt in Würtemberg, and died at Ratisbon in November 1631[1]—eleven years before the birth of Sir Isaac Newton. In addition to his researches on the motions of the Solar System, Kepler published some views on the construction of the heavens in a work entitled *The Epitomy*, the first volume of which was published in 1618, and the fourth volume in 1620.

In this work Kepler expresses the opinion that the Sun is at a greater distance from the fixed stars than they are from each other, and that he is situated in an exceptional position in the universe, but not far from the centre of the stellar ring which forms the Milky Way. This latter conclusion he deduced from the fact that the Galaxy presents the appearance of a great circle of the celestial sphere, and of nearly uniform brightness throughout the whole of its extent. He considers the visible heavens as forming a spherical shell of which the interior surface is the boundary of the vacant space containing the Sun and Solar System, and the shell itself possibly formed of ice or crystal which bounds the visible universe from the void of space! He considered that the stars are very much smaller than the

[1] In 1870 a handsome monument was erected to his memory in his native town.

Sun, and shine by their own inherent light, but that possibly the Sun is merely one of the fixed stars, which may also form the centres of planetary worlds.

With reference to this generalisation, however, he seems to have entertained considerable doubt, as it did not necessarily form a consequence of the Copernican system of astronomy; and he appears to have rather preferred the hypothesis that the stars are scattered in a bed of a thin and watery nature, possibly frozen solid by the intense cold due to its great distance from the Sun! These visionary speculations—a curious jumble of truth and fable—seem to have been advanced by Kepler as an attempt to reconcile his views of the construction of the heavens with "the waters above the firmament," spoken of in the first chapter of Genesis.

Kepler estimated the probable dimensions of the universe in the following way. Taking Saturn, the farthest known planet at that time, he finds that the radius of its orbit is about 2000 times that of the solar globe, and concludes from the "harmony of relations" that the distance of the fixed stars ought to be again 2000 times the distance of Saturn from the Sun, a result which he considered to be confirmed by the observations of Tycho Brahé, who showed that the stars had no sensible parallax.

The distance thus found—about $1\frac{3}{4}$ billion of miles—falls far short of the distance of the nearest fixed stars, as indicated by modern observations; but it seems worth remarking that, if we take the case of Neptune—the outermost planet now known—of which the mean distance from the Sun is about 2792 millions of miles, the distance of the stars computed by Kepler's method comes out about

18 billions of miles, a distance not very much less than that of α Centauri, as deduced from recent measures of its parallax.

Kepler supposes the total mass of the universe to be divided into three portions: one third being concentrated in the body of the Sun, one third contained in the planets and the ether, which fills the void space round the Sun, and the remaining third forming the crystalline sphere of the fixed stars. From these data he calculates the thickness of this crystalline shell, and finds it only $\frac{1}{60000}$ of the Sun's radius—about 7 miles! These views certainly seem very visionary when read in the light of modern researches.

In a posthumous work by Huygens, entitled *Cosmotheros*, published in 1698, three years after his death, he propounds the identity in constitution of the Sun and fixed stars, and supposes a uniform distribution of stars in space, out to an infinite distance, each star forming, like the Sun, the centre of a planetary system. He seems to have thought the determination of stellar distance by astronomical observations to be impossible; but by means of a photometric comparison between the light of the Sun and Sirius, he estimates the distance of that star at about 28,000 times the Sun's distance from the earth, a result very much smaller than that derived from modern observations. Kepler offers no opinion with reference to the Milky Way.

We next come, in order of time, to Thomas Wright of Durham, to whom seems certainly due the original conception of the "disc" or "grindstone" theory of the Milky Way, a theory usually attributed to Sir W. Herschel. This theory was first published in 1750 in a work of which the full title is as follows: "An Original Theory or New

Hypothesis of the Universe, Founded upon the Laws of Nature, and solving by Mathematical Principles the General Phænomena of the Visible Creation ; and particularly The Via Lactea. Compris'd in Nine Familiar Letters from the Author to his Friend. And Illustrated with upwards of Thirty Graven and Mezzotinto Plates, By the Best Masters. By Thomas Wright of Durham." This work is very rare. Even the great library of Poulkova does not possess a copy, and it appears from the writings of Kant, Struve, and Arago that neither of them had seen an original copy of Wright's work. On the title-page of the copy belonging to the Library of the Royal Astronomical Society (from which I have derived the following particulars) there is a manuscript note by Professor De Morgan,[1] in which he says that he had only seen three copies of the work, one of which " had an ingenious attempt to alter MDCCL into MDCCC, which could only be detected by looking through the back of the page,"—an attempt possibly made by some unscrupulous person to try and prove that Wright's views were not published till 1800, or a date subsequent to the appearance of Sir W. Herschel's earlier papers.[2]

Thomas Wright was born on September 22nd, 1711, at Byer's Green, about six miles from Durham. He was the son of a carpenter and small landowner. In his early days he was apprenticed to a clockmaker, and was employed as a maker of mathematical instruments. He then went to sea, and afterwards worked as a maker of almanacs, and a lecturer and teacher of mathematics. Subsequently he appears to have attained some affluence, for he built a

[1] Author of *The Budget of Paradoxes.*

[2] Wright died in 1786.

handsome house at Byer's Green, the place of his birth, and died there on February 25th, 1786. He seems to have been an observer, especially of comets, and a calculator of their orbits. He published some other works, and acquired such a reputation by his writings on navigation that in 1742 he was offered the professorship of navigation in the Imperial Academy of St. Petersburg.[1]

In the first letter of the work above referred to he alludes to the writings of previous authors, and mentions that his own views were the result of his "Astronomical Studies full fifteen years ago" (or in the year 1735). In the second letter he deals with the "Nature of Mathematical Certainty, and the various Degrees of Moral Probability proper for Conjecture," and describes the various theories of the ancient and mediæval astronomers previous to the publication of the Copernican system. The third letter treats of the "Nature, Magnitude and Motions of the Planetary Bodies round the Sun, etc."; but his figures—owing to the incorrect determination of the Sun's distance from the earth, as then known[2]—are of course inaccurate.

In this letter he hazards the conjecture "that the Comets in general, through all their respective Orbits, describe one common Area, that is to say, all their Orbits with regard to the Magnitude of their proper Planes, are mathematically equal to one another," a prediction which has not been verified by modern observations. His discussion of the nature of the heavenly bodies is continued in the fourth letter, in which he expresses the opinion that "the

[1] I am indebted for the above particulars to an interesting paper by Professor De Morgan in the *Philosophical Magazine* for April 1848.

[2] He assumes the Sun's distance at 81 millions of miles.

Sun is a vast Body of blazing Matter," and argues from analogy that the stars are similar in constitution to the Sun, and surrounded by attendant planets similar to those which constitute our Solar System. He justly remarks: "If the Stars were ordained merely for the Use of us, why so much Extravagance and Ostentation in their Number, Nature and Make? For a much less Quantity, and smaller Bodies placed nearer to us, would every Way answer the vain End we put them to; and besides, in all Things else, Nature is most frugal, and takes the nearest Way, through all her Works, to operate and effect the Will of God."

In the fifth letter we find the first allusion to the Milky Way, of which he says:—

"This amazing Phænomenon which have been the Occasion of so many *Fables*, idle Romances, and ridiculous Opinions amongst the Antients, still continues to be unaccounted for, and even in an Age vain enough to boast Astronomy in its utmost Perfection. . . . This luminous Circle has often engrossed my Thoughts, and of late has taken up all my idle Hours; and I am now in great Hopes I have not only at last found out the real Cause of it, but also by the same Hypothesis, which solves this Appearance, shall be able to demonstrate a much more rational Theory of the Creation than hitherto has been anywhere advanced, and at the same Time give you an intire new Idea of the Universe, or infinite System of Things. This most surprising Zone of Light, which have employed successively for many Ages past, the wisest Heads among the Antients, to no other purpose than barely to describe it; we find to be a perfect Circle,[1] and nearly bisecting the celestial Sphere, but very irregular in Breadth and Brightness, and in many places divided into double Streams."[1]

The opinions of the ancients are then referred to, and he gives two plates showing the general appearance of the

[1] This agrees well with modern observations. But of course any one with good sight could have seen the Milky Way hundreds of years ago as it appears to-day.

Milky Way to the naked eye in the Northern and Southern Hemispheres. These drawings, although fairly well executed, show little or no details, and represent the Galactic stream in many places much too narrow.[1] He also gives plates showing selected portions of the Milky Way in Antinous and Perseus, and one of the Pleiades, as observed by himself with a small reflecting telescope. From these and the observations of others he concludes "that this Zone of light proceeds from an infinite Number of small Stars." Assuming the mean width of the Galaxy at 9 degrees, "and supposing only twelve hundred Stars in every square degree," he obtains a total of 3,888,000 stars.

He refers to the division of stars into magnitudes, and says: "The first Degree, or that of the largest Magnitude, we give to SYRIUS, the second to ARCTURUS, the third to ALDEBARAN, the fourth to LYRA, the fifth to CAPELLA, the sixth to REGULUS, the seventh to RIGEL, the eighth to FOMAHAUNT (*sic*), and the ninth to ANTARUS: These are all said to be of the first Class; and besides which, there are at least, within the Reach of our latest improved Opticks, nine more Denominations within the Radius of the visible Creation." The order of brightness given by Wright does not, however, agree well with modern observations, especially in the position he assigns to Aldebaran—brighter than Lyra (Vega) and Capella, which it certainly is not, at least at the present day.

From a consideration of the distance to which some comets recede from the Sun at aphelion, and assuming

[1] He assumes the mean width of the Milky Way at only nine degrees (p. 42).

Sirius as the nearest fixed star,[1] he finds for "the Radius of the visible Creation," including stars of the sixth magnitude, 6,000,000,000,000 miles, and for stars of the ninth magnitude 9,000,000,000,000 miles. He adds, however, that "this computation supposes a mean common Distance of the Stars in a sort of Syzygia or Direction of a Right Line, which is not the real Case; for the Stars cannot be supposed to diminish in a proportional Magnitude by any mathematical *Ratio*, but by some geometrical, or rather musical one; for Instance, if the Distance of a first be 3, that of a second should be about 5, and of a proportional Third, 8,333, &c., *ad infinitum*." In this fifth letter Wright gives a "*Table of several new Stars*, Nebulæ, *and double Stars*, etc." (in which he includes the "lost Pleiad"), Mira (*o*), Ceti, and χ Cygni[2] ("A new star in the swan's neck"), etc.[2]

The sixth letter treats "Of General Motion amongst the Stars, the Plurality of Systems, and Innumerability of Worlds." From the appearance of the Milky Way he argues

"that the Stars are not infinitely dispersed and distributed in a promiscuous Manner throughout all the mundane Space, without Order or Design, is evident beyond a Doubt from this vast collective Body of Light, since no such Phænomenon could possibly be produced by Chance or exhibited without a designed Disposition of its constituent Bodies." "If any regular Order of the Stars can then be demonstrated that will naturally prove this Phænomenon to be no other than a certain Effect arising from the Observer's Situation, I think you must of course grant such a Solution at least rational, if not the Truth;

[1] From a photometric comparison between Sirius and the Sun made by Huygens, Wright finds the distance of Sirius = 2,213,120,000,000 miles. This number he considers "much too large," but we now know it to be *far too small*—probably not $\frac{1}{10}$th of the real distance.

[2] He says this "was seen at its highest" September 10th, 1714.

and this is what I propose by my new Theory." "To a Spectator placed in an indefinite Space, all very remote Objects appear to be equally distant from the eye; and if we judge of the *Via Lactea* from Phænomena only, we must of course conclude it a vast Ring of Stars, scattered promiscuously round the celestial Regions in the Direction of a perfect Circle."

He then proceeds to consider the stars as suns, attended by planets and comets, similar to the Solar System, and scattered through infinite space. He conceives them all to be in motion, and discusses the proper motion of Arcturus and other stars as deduced from the observations of Hipparchus, Tycho Brahé, Hevelius, and Flamsteed. He gives drawings of the Pleiades and some stars in Perseus, from his own observations made by "a Combination of Triangles," and suggests that by a comparison of these with future drawings proper motion may be detected.

In the seventh letter we at last reach his theory of the Milky Way. This letter is headed "*The Hypothesis or Theory, fully explained and demonstrated, proving the sidereal creation to be finite.*"[1] To avoid any misrepresentation or misapprehension of Wright's views on the subject it will perhaps be better to quote his words in full, especially as his work is so little known. He says (p. 61):—

"The Majesty, Power and Dominion of GOD is best displayed in the external Direction of Things, his Wisdom and visible Agency in the internal: Hence by proper Objects, selected from both, attended with just Reflections, we may certainly raise our Ideas almost to the Pitch of Immortals; but how far the human Imagination may possibly go, or how much Minds like ours may be improved, is a

[1] From this it will be seen that my view of the *visible* universe of stars, being limited in extent, was originally held by Wright.

Question not easily determined; but as natural Knowledge evidently increases daily, and astronomical Enquiries are the most capable of opening our Minds, and enlarging our Conception, of consequence they must be most worthy our Attention of all other Studies. But of this I have said enough, and think it is now more than Time to attempt the remaining Part of my Theory."

"When we reflect upon the various Aspects and perpetual Changes of the Planets, both with regard to their heliocentric and geocentric Motion,[1] we may readily imagine, that nothing but a like eccentric Position of the Stars could any way produce such an apparently promiscuous Difference in such otherwise regular Bodies. And that in like manner, as the Planets would, if viewed from the Sun, there may be one Place in the Universe to which their Order and primary Motions must appear most regular and most beautiful. Such a Point, I may presume, is not unnatural to be supposed, altho' hitherto we have not been able to produce any absolute Proof of it. See *Plate* XXV." [Section of a spherical shell of stars.]

"This is the great Order of Nature, which I shall now endeavour to prove, and thereby solve the Phænomena of the *Via Lactea*; and in order thereto, I want nothing to be granted but what may easily be allowed, namely, that the *Milky Way* is formed of an infinite number of small Stars."

"Let us imagine a vast infinite Gulph, or Medium, every Way extended like a Plane, and inclosed between two Surfaces, nearly even on both Sides, but of such a Depth or Thickness as to occupy a Space equal to the double Radius, or Diameter of the visible Creation, that is to take in one of the smallest Stars each Way, from the middle Station, perpendicular to the Plane's Direction, and, as near as possible, according to our Idea of their true Distance." [Here we have the "disc" theory clearly propounded.]

"But to bring this Image a little lower, and as near as possible level to every Capacity, I mean such as cannot conceive this kind of continued Zodiack, let us suppose the whole Frame of Nature in the Form of an artificial Horizon of a Globe, I don't mean to affirm that it is really so in Fact, but only state the Question thus, to help your Imagination to conceive more aptly what I would explain. *Plate*

[1] "Not to mention their several Conjunctions and Apulces to fixed stars, &c., see the State of the Heavens in 1662, *December* the first, when all the known planets were in one Sign of the Zodiac, *viz.*, *Sagittarius*."

XXIII. will then represent a just section of it.[1] Now in this Space let us imagine all the Stars scattered promiscuously, but at such an adjusted Distance from one another, as to fill up the whole Medium with a kind of regular Irregularity of Objects. And next let us consider what the Consequence would be to an Eye situated near the Center Point, or anywhere about the middle Plane, as at the point A. Is it not, think you, very evident, that the Stars would there appear promiscuously dispersed on each Side, and more and more inclining to Disorder, as the Observer would advance his Station towards either Surface, and nearer to B and C [the limits of the thickness], but in the Direction of the General Plane towards H or D, by the continual Approximation of the visual Rays, crowding together as at H, betwixt the limits D and G, they must infallibly terminate in the utmost Confusion. If your Opticks fail you before you arrive at these external Regions, only imagine how infinitely greater the Number of Stars would be in those remote Parts, arising thus from their continual crowding behind one another, as all other Objects do towards the Horizon Point of their Perspective, which ends but with Infinity: Thus, all their Rays at least so near uniting, must meeting in the Eye appear, as almost, in Contact, and form a perfect Zone of Light; this I take to be the real Case, and the true Nature of our *Milky Way*, and all the Irregularity we observe in it at the Earth, I judge to be intirely owing to our Sun's Position in this great Firmament, and may easily be solved by his Eccentricity and the Diversity of Motion that may naturally be conceived amongst the Stars themselves, which may here and there, in different Parts of the Heavens, occasion a cloudy Knot of Stars, as perhaps at E."

"But now to apply this Hypothesis to our present Purpose, and reconcile it to our Ideas of a circular Creation, and the known Laws of orbicular Motion, so as to make the Beauty and Harmony of the Whole consistent with the visible Order of its Parts, our Reason must now have recourse to the Analogy of Things. It being once agreed, that the Stars are in Motion, which, as I have endeavoured in my last Letter to show, is not far from undeniable Truth, we must next consider in what Manner they move. First then, to suppose them to move in right Lines, you know is contrary to all the Laws

[1] This Plate—incorrectly numbered XXI.—represents a stratum of stars comparatively thin, but of indefinite extension in its general plane, with the Sun placed near the centre of the thickness.

and Principles we at present know of; and since there are but two Ways that they can possibly move in any natural Order, that is, either in right Lines, or in Curves, this being one, it must of course be the other, *i.e.* in an Orbit; and consequently, were we able to view them from their middle Position, as from the eye seated in the Center of *Plate* XXV.[1], we might expect to find them separately moving in all manner of Directions round a general Center, such as is there represented. It only now remains to show how a Number of Stars, so disposed in a circular Manner round any given Center, may solve the Phænomena before us. There are but two Ways possible to be proposed by which it can be done, and one of which I think is highly probable; but which of the two will meet your Approbation, I shall not venture to determine, only here inclosed I intend to send you both. The first is in the Manner I have above described, *i.e.* all moving in the same Way, and not much deviating from the same Plane, as the Planets in their heliocentric Motion do round the Solar Body. In this Case the primary, secondary, and tertiary constituent Orbits, &c., framing the Hypothesis, are represented in *Plate* XXII.,[2] and the Consequence of such a Theory arising from such an universal Law of Motion in *Plate* XXIII.,[2] where B, D denotes the local Motion of the Sun in the true *Orbis Magnus*, and E, C that of the Earth in her proper secondary Orbit, which of course is supposed, as is shewn in the Figure to change its sidereal Positions, in the same Manner as the Moon does round the Earth, and consequently will occasion a Kind of Procession, or annual Variation in the Place of the Sun, not unlike that of the Equinoxes, or Motion of all the Stars together, from West to East round the Ecliptic Poles, and probably may in some Degree be the Occasion of it. [Here Wright is quite mistaken. The Precession of the Equinoxes has nothing whatever to do with solar motion round a Central Sun.—J. E. G.] This Angle is represented, but much magnified, by the lines F, C, G, and the Unnaturalness, or Absurdity of a right Line Motion of the Sun by the Line I, H."

"The second Method of solving this Phænomenon, is by a spherical

[1] An eye situated in the centre of a hollow sphere, the thickness of the shell being filled with stars.

[2] There is some confusion in the numbering of the plates in this letter, but the diagrams referred to above represent the earth revolving round the Sun, which again revolves round a Central Sun.

Order of the Stars, all moving with different Direction round one common Center, as the Planets and Comets together do round the Sun, but in a kind of Shell, or concave Orb. The former is easily conceived, from what has been already said, and the latter is as easy to be understood, if you have any Idea of the Segment of a Globe, which the adjacent Figures will, I hope, assist you to. The Doctrine of these Motions will perhaps be made obvious to you, by inspecting the following Plates. PLATE XXIV. is a Representation of the Convexity, if I may call it so, of the intire Creation, as a universal Coalition of all the Stars consphered round one common Center, and as all governed by one and the same Law [external view of a spherical shell of stars].

"PLATE XXV. is a central Section of the same, with the Eye of Providence seated in the Center, as in the Virtual Agent of Creation.

"PLATE XXVI. represents a Creation of a double Construction, where a superior order of Bodies C, may be imagined to be circumscribed by the former one A, as possessing a more eminent Seat, and nearer the supream Presence, and consequently a more perfect Nature [a spherical shell of stars within a second spherical shell]. Lastly,

"PLATE XXVII. represents such a Section and Segments of the same, as I hope will give you a perfect Idea of what I mean by such a Theory. *Fig.* 1 is a corresponding Section of the part at A in *Fig.* 2, whose versed Sine is equal to half the thickness of the starry Vortice A C, or B A. Now I say, by supposing the Thickness of this Shell, 1. you may imagine the middle Semi-chord A D, or A E, to be nearly 6; and consequently thus in a like regular Distribution of the Stars, there must of course be at least three Times as many to be seen in this Direction of the Sine or Semi-chord A E itself, than in that of the semi-versed Sine A C, or[1] where near the Direction of the Radius of the Space G. Q. E. D."

"But we are not confined by this Theory to this Form only, there may be various Systems of Stars, as well as of Planets, and differing probably as much in their Order and Distribution as the Zones of *Jupiter* do from the Rings of *Saturn*, it is not at all necessary, that every collective Body of Stars should move in the same Direction, or after the same Model of Motion, but may as reasonably be supposed as much to vary, as we find our Planets and Comets do."

"Hence we may imagine some Creations of Stars may move in

[1] The word "any" is perhaps omitted here.

the Direction of perfect Spheres, all variously inclined, direct and retrograde; others again, as the primary Planets do, in a general Zone or Zodiack, or more properly in the Manner of *Saturn's* Rings, nay, perhaps Ring within Ring, to a third or fourth Order, as shown in *Plate* XXVIII., nothing being more evident, than that if all the Stars we see moved in one vast Ring, like those of *Saturn*, round any central Body, or Point, the general Phænomena of our Stars would be solved by it; see *Plate* XXIX., *Figs.* 1 and 2, the one representing a full Plane of these Motions, the other a Profile of them, and a visible Creation at B and C, the central Body A, being supposed as *incognitum*, without the finite View; not only the Phænomena of the *Milky Way* may be thus accounted for, but also the cloudy Spots, and irregular Distribution of them; and I cannot help being of Opinion, that could we view *Saturn* thro' a Telescope capable of it, we should find his Rings no other than an infinite Number of lesser Planets, inferior to those we call his Satellites. [This is the now generally accepted theory of the constitution of Saturn's rings. —J. E. G.] What inclines me to believe it, is this, this Ring, or Collection of small Bodies, appears to be sometimes very eccentric, that is, more distant from *Saturn's* Body on one Side than on the other, and as visibly leaving a larger Space between the Body and the Ring; which would hardly be the Case, if the Ring, or Rings, were connected, or solid, since we have good Reason to suppose, it would be equally attracted on all sides by the Body of *Saturn*, and by that means preserve everywhere an equal Distance from him; but if they are really little Planets, it is clearly demonstrable from our own in like Cases, that there may be frequently more of them on one Side than on the other, and but very rarely, if ever, an equal Distribution of them all round the *Saturnian* Globe."

"How much a confirmation of this is to be wished, your own Curiosity may make you judge, and here I leave for the Opticians to determine. I shall content myself with observing that Nature never leaves us without a sufficient Guide to conduct us through all the necessary Paths of Knowledge; and it is far from absurd to suppose Providence may have everywhere throughout the whole Universe, interspersed Modules of every Creation, as our Divines tell us, Man is the image of God himself."

"Thus, Sir, you have had my full Opinion, without the least Reserve, concerning the visible Creation, considered as Part of the

finite Universe; how far I have succeeded in my designed Solution of the *Via Lactea*, upon which the Theory of the Whole is formed, is a Thing will hardly be known in the present Century, as in all Probability it may require some Ages of observation to discover the Truth of it."

From this it is clear that Wright's views—contained in the first portion of the preceding extract—are exactly in agreement with the "grindstone," or "disc," theory of the Milky Way, afterwards propounded by Sir W. Herschel from the results of his telescopic gauges of the heavens, but which was subsequently abandoned by that great astronomer himself, as will be shown in the following chapters.

Wright's ideas about a central sun are now known to be improbable. We see in the globular clusters a number of stars collected into separate systems, but, as far as we can perceive, containing no body of sufficiently large proportions to enable it to play the part of a central sun.

From the latter portion of the preceding extract it will be seen that Wright considered the "visible creation" as not only finite, but as forming "part of the finite universe." That the *visible* universe is most probably of finite extent will be shown in a subsequent chapter.

The eighth letter of Wright's work is entitled "*Of Time and Space with regard to the Known Objects of Immensity and Duration*," and letter the ninth "*Reflections by Way of General Scholia, of Consequences relating to the Immortality of the Soul, and concerning Infinity and Eternity.*" These have, however, no especial bearing on our present subject.

We next come to the views of the famous German philosopher Immanuel Kant, founder of the transcendental

school of philosophy, and author of the work *Kritik der reinen Vernunst* (Critic of the Pure Reason). Kant was born in 1724, and died in 1804. In the year 1755 he published a work entitled *Allgemeine Naturgeschichte und Theorie des Himmels, oder Versuch von der Verfassung und dem mechanischen Ursprunge des ganzen Weltgebäudes nach Newtonischen Grundsätsen abgehandelt.* In the preface to this work the author proposes "to discover the arrangement which unites the great members of the creation in all its extent to infinity, and to deduce by the aid of mechanical laws the formation of the celestial bodies, and the origin of their movements from the primitive state of nature."

This work seems to have been unknown to Lambert,[1] whose views—published in 1760—will be considered further on. Kant admits that his ideas of stellar arrangement were first suggested to him by a perusal of Wright's views [he did not, however, see an original copy of Wright's work, but obtained his knowledge of the memoir from a Hamburg journal published in 1751], but states that he could not say exactly how far his views were a repetition or amplification of Wright's hypothesis.

Kant seems disposed to consider the universe as infinite in extent, and containing an infinite number of worlds, and says that "we approach no nearer to an Almighty Creator in supposing the Universe limited to a sphere bounded by the Milky Way than in restricting his creative power to the interior of a ball of one inch in diameter."

[1] Kant states in a note to his treatise of 1763 that his work on the "natural history of the sky" was unknown to Lambert at the time of the publication of his cosmological letters.

According to Kant's view of the universe, all the visible stars are suns forming the centres of planetary systems similar to our own, ruled by gravitation, which, however, is not confined to each system, but extends from one system to another, all forming a system of a higher order, that of the Milky Way. The observed proper motions of some of the fixed stars seemed to him to show that the stars are, like the planets, members of a system.

Kant considered that the system of the Milky Way, in which the component stars are apparently aggregated towards a general plane, affords a striking analogy to the Solar System, in which all the planets perform their revolutions round the Sun in orbits but little inclined to one plane, namely, that of the Ecliptic. He thinks that the Milky Way system includes all the stars scattered over the celestial vault, and notes the tendency of the naked-eye stars to crowd towards the Galactic Zone.[1]

As in the Solar System there is a principal and central body—the Sun—so Kant thought it probable that a large body exists also in the centre of the Milky Way. The mass of this central sun would probably, he thought, be proportional to the grandeur of the system of which it formed the centre, and Kant asks whether it should not be easily recognised by its superior brilliancy. To this he replies that there is no reason to expect that a central body of this kind would shine as a brilliant star. Were it a million times larger than our Sun, it would not appear brighter than Sirius if placed at a distance 100 times

[1] This seems to be the first suggestion of the aggregating tendency of the lucid stars on the Galaxy, a fact now generally recognised by astronomers.

greater, and he thought it probable that Sirius itself was the central sun.[1]

Kant considered that the Milky Way is not a unique system of its kind, but that the elliptical nebulæ which the telescope fails to resolve into stars are probably similar systems reduced to a small apparent diameter by immensity of distance, and indicating by their oval form the existence of a principal plane, as in the Milky Way.[2] He goes a step further and supposes that all these Milky Ways have a relation to each other analogous to the suns of our system, thus forming a system of a higher order, and so on to vaster systems of an order higher still.

Kant thought that Lambert's views agreed exactly with his own; but there are, in many points, important differences in the hypotheses advanced by the two writers.

Lambert's views were first published in 1760, in a work entitled *Photometria*, in which he terms the Milky Way "the ecliptic of the fixed stars," and expresses the opinion that the Galaxy is formed of a great number of systems, each containing a multitude of suns. From a comparison of the brightness of the fixed stars with that of the planets, especially Saturn, he estimates the distance of stars of the first magnitude, and finds it more than 425,000 times the Sun's distance from the earth, a result in agreement with the observations of Bradley, who made the parallax smaller than half a second of arc. Modern measures confirm the accuracy of this conclusion.

[1] Recent researches render this supposition very improbable.

[2] The modern discovery of the gaseous nature of some of these elliptical nebulæ is of course against the truth of Kant's hypothesis.

Lambert's complete theory appeared the following year, 1761, in a work entitled *Cosmologische Briefe über die Einrichtung des Weltbaues. Ausgefertigt von F. H. Lambert. Augsburg* 1761.

As in Kant's hypothesis, Lambert considers the stars as suns, accompanied by planets and comets, like our own Sun, each of these suns with their family of attendants forming a system of the first order. All the visible stars, with exception of those forming the Milky Way, constitute a system of the second order. Of this system our Sun is a member. Of systems of the second order he supposes a great number, not scattered irregularly through space, but ranged one behind the other in the vicinity of the Galactic plane, and forming by their aggregation the aspect of the Milky Way. This forms a system of the third order, which is therefore not spherical, but oblong, or a disc whose diameter is immensely greater than its thickness. It will be seen that this hypothesis somewhat resembles that of Wright and the "disc" theory of Sir W. Herschel's earlier papers. Lambert considered that this constitution of the Milky Way is indicated by the irregularity of the Galactic stream, by its variable density, and its branching ramifications. Modern observations, however, do not lend much support to this daring hypothesis.

Extending the analogy, Lambert supposes that in the universe there may be a great number of Milky Ways, which combined form a system of the fourth order, of which the Orion nebula[1] is possibly a near one. He continues the idea to systems of the fifth and higher orders, and

[1] The now known gaseous constitution of this nebula is of course in opposition to Lambert's hypothesis.

considers that all these systems are linked together by the bonds of universal gravitation.

As in the Solar System the planets are separated by distances immensely great compared to the smaller system formed by a planet with its satellites, so between the suns forming a system of the second order there exists, Lambert thinks, a distance enormously great in comparison with the dimensions of each solar system. The relative proportion is supposed to be continued between the constituent members of systems of the third and higher orders.

Lambert estimated that the number of stars included in the cluster of which our Sun forms a member is about one and a half million, and that the distance of the nearest stars of the Milky Way is about 750 times the distance of Sirius. These estimates seem to have been based on rather insufficient data. Lambert considered that the isolation of our cluster from the Milky Way is shown by the sharp boundaries of the Galactic Zone as seen in the sky. In reality, however, no such sharp limits exist. This is clearly shown by Sir W. Herschel's gauges, and by Dr. Boeddicker's drawing of the Milky Way. Indeed any one with good eyesight can see at a glance that the boundaries of the Milky Way are very ill defined.

Lambert did not consider the Milky Way as infinite in extent in the direction of its principal plane, and he estimates the distance of its remotest stars at about 150,000 times the distance of Sirius. He seems to forget, however, that stars at this vast distance would not be visible in the largest telescope that could possibly be constructed.

According to Lambert the Sun is not placed exactly in

the centre of his cluster, but is not distant from the centre more than a few distances of Sirius,[1] this centre being probably situated in the direction of Sirius or Canis Major.

From the observed proper motions of the stars, Lambert infers that all the bodies of our cluster are ruled by the laws of gravitation, and are acted on by a central force. These observed motions also indicated, he thought, a proper motion of the Sun himself, and suggested that by careful observations we might be able to determine the position of the sky towards which the Sun is moving. This remarkable prediction has since been fully verified. From the analogy of the Solar System, in which the simplicity of the motions of the planets and comets is due to the enormous mass of the central body, Lambert supposes that the cluster of which our Sun forms a member is ruled by a great central sun. He argues that in a vast cluster without a central body, the motions, owing to the combined attractions of the components, would be very complicated, and would lack the simplicity we observe in the planetary system. He even doubts that the stability of such a system would be possible without the presence of a central sun, and suggests that it may possibly be invisible to us on account of being an opaque body, or perhaps shining only by light reflected from the nearest of the suns forming the cluster. For the whole of the Milky Way he also supposes the existence of a central sun of proportionately larger dimensions. Sir John Herschel has, however, shown that in a globular cluster a central body is not necessary, as dynamical stability would be insured by each component

[1] This opinion agrees with Struve's researches on the subject, which will be discussed in a subsequent chapter.

describing its own ellipse round the centre of gravity of the system.

We have lastly to refer to the views of the Rev. John Michell, which were published in 1767 in a paper (*Philosophical Transactions* of the Royal Society, vol. lvii., pp. 234-64) with the title "*An Inquiry into the probable Parallax and Magnitude of the Fixed Stars from the Quantity of Light which they afford us, and the particular Circumstances of their Situation.*"

Michell estimates—as Lambert did seven years previously [1]—the probable distance of Sirius, by a comparison of its light with that of the Sun, by the intervention of the planet Saturn, and arrives at the conclusion that the parallax of Sirius is smaller than a second of arc, a result fully confirmed by modern measures [Gyldén found a parallax of 0·″193; Belopolsky and Wagner, 0·″43; Gill 0·″37, and Elkin 0·″41. The larger values are probably the best]. He considers that the apparent diameter of the fixed stars could never be measured, as it is probably smaller than $\frac{1}{50}$th of a second, so that a magnifying power of at least 12,000 times would be necessary to show it with a visible disc [a conclusion probably correct]. From some rough experiments he estimates that stars of the sixth magnitude are at distances 20 to 30 times greater than that of Sirius, and he deduces for these a parallax of 0·″05 to 0·″03.

Although the division of the stars into constellations is arbitrary, Michell thinks that there is a well-marked tendency to aggregate into natural groups in various parts

[1] Lambert's researches on this subject and Kant's speculations seem to have been unknown to Michell.

of the sky; for instance, in the Pleiades and the double cluster in Perseus. He found that the mathematical probability of the proximity of the two stars β^1 and β^2 Capricorni being the result of accident is only $\frac{1}{80}$, and for the six stars in the Pleiades only $\frac{1}{500000}$ [that is, the chances are 500,000 to 1 against the close arrangement of the visible stars in the Pleiades being the result of accident]. He therefore considers that closely grouped stars are linked together by the laws of gravitation, or some other law of force impressed on them by their Creator, and that the double, triple, and multiple stars also form connected systems. He looked on the nebulæ as clusters placed at a vast distance from our system, and on nebulous stars as systems composed of a very large central sun, surrounded by a great number of others, too small to be individually visible. Observations with the spectroscope, however, have shown that these conclusions, with reference to the nebulæ, are not *generally* admissible, many of them being certainly gaseous.

Michell considered it probable that the Sun forms a member of an isolated group, which includes all the brighter stars, those of lesser brightness which telescopes show to be situated in an isolated space, and most of the stars of a red colour. He includes the red stars on the supposition that they are in reality larger than white stars of the same apparent brightness; and he thought that the cluster might perhaps include about 350 stars. This hypothesis is similar to the theory advanced by Sir J. Herschel and Dr. Gould that the Solar System forms part of a small cluster (of "less than 500 stars") distinct from the Milky Way (see Chapter IX.). Michell supposed his

view to be strengthened by the proper motions observed among stars of the first magnitude, but modern observations show that the largest proper motions are found among stars of the fifth and fainter magnitudes.

Like Lambert, Michell considered the apparent stellar motions to be due to a real motion of the stars themselves, compounded with an apparent motion caused by the Sun's motion in space, and the correctness of this has been fully confirmed by modern researches.

Curiously enough Michell does not venture any opinion on the constitution of the Milky Way.

Michell's speculations are very favourably referred to in Sir W. Herschel's writings. The researches and theories of this great astronomer will form the subject of the next chapter.

CHAPTER XIV.

SIR WILLIAM HERSCHEL'S THEORIES.

"A knowledge of the construction of the heavens has always been the ultimate object of my observations."[1]—SIR W. HERSCHEL.

THE remarkable and interesting researches of Sir William Herschel on the construction of the stellar heavens are contained in a set of 73 memoirs scattered through 39 volumes of the *Philosophical Transactions of the Royal Society* from 1780 to 1818. A concluding paper on the subject is found in the first volume of the publications of the Royal Astronomical Society, of which Herschel was the first president.

Herschel's investigations had for their object the following subjects of stellar astronomy[2]:—

1. The nature of the Sun and fixed stars; the brightness of the stars; variable stars, etc.
2. The distances of the fixed stars.
3. The proper motion through space of the stars and Solar System.
4. Double and multiple stars.
5. Clusters of stars and nebulæ.

[1] *Philosophical Transactions*, 1811, p. 269.

[2] Most of the details in this chapter are derived from Struve's *Études d'Astronomie Stellaire*.

6. The construction of the heavens ; the Milky Way, etc.

Although all these sections of sidereal astronomy have a bearing on the subject of the present volume, the last of them is the one most closely connected with the matter at present under consideration.

Herschel's first general views are given in two memoirs published in 1784 and 1785 "On the Construction of the Heavens." These views are explained by his famous son, Sir John Herschel, in the following words :—

"If the comparison of the apparent magnitudes of the stars with their numbers leads to no immediately obvious conclusion, it is otherwise when we view them in connection with their local distribution over the heavens. If indeed we confine ourselves to the three or four brightest classes, we shall find them distributed with a considerable approach to impartiality over the sphere : a marked preference, however, being observable, especially in the Southern Hemisphere, to a zone or belt, following the direction of a great circle passing through ϵ Orionis and α Crucis. But if we take in the whole amount visible to the naked eye, we shall perceive a great increase of number as we approach the borders of the Milky Way. And when we come to telescopic magnitudes, we find them crowded beyond imagination, along the extent of that circle, and of the branches which it sends off from it ; so that in fact its whole light is composed of nothing but stars of every magnitude, from such as are visible to the naked eye down to the smallest points of light perceptible with the best telescopes."

"These phænomena agree with the supposition that the stars of our firmament, instead of being scattered in all directions indifferently through space, form a stratum of which the thickness is small, in comparison with its length and breadth ; and in which the earth occupies a place somewhere about the middle of its thickness, and near the point where it subdivides into two principal laminæ, inclined at a small angle to each other. For it is certain that, to an eye so situated, the apparent density of the stars, supposing them pretty equally scattered through the space they occupy, would be least in the direction of the visual ray, as S A, perpendicular to the lamina, and greatest in that of its breadth, as S B, S C, S D ; increasing rapidly in

passing from one to the other direction, just as we see a slight haze in the atmosphere thickening into a decided fog bank near the horizon, by the rapid increase of the mere length of the visual ray. Such is the view of the construction of the starry firmament taken by Sir William Herschel, whose powerful telescopes first effected a complete analysis of this wonderful zone, and demonstrated the fact of its entirely consisting of stars. . . . The immense distances at which the remoter regions must be situated will sufficiently account for the vast predominance of small magnitudes which are observed in it."[1]

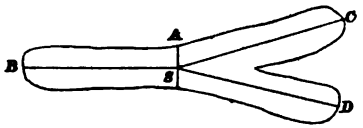

Fig. 12.

Let us now consider the methods adopted by Herschel to arrive at the form and extent of the Milky Way. If we suppose the stars to be uniformly distributed through a space extended to the same distance in all directions, with the observer's eye placed nearly in the centre, it is evident that the number of stars visible in the field of a telescope directed to different portions of the stellar vault would be nearly the same for every position of the telescope. But let us suppose that the stars are equally distributed, not in a sphere, but in the form of a cylindrical disc, of a small thickness in comparison with its diameter. In this case—if the stars near the borders of the disc are within the range of our telescope—there will be seen in the direction of the diameter of the disc a very large number of stars, and in that of the thickness, or axis of the disc, a comparatively small number. In other directions the number visible would be proportional to the length of the visual ray. It follows, therefore, that an enumeration of the stars visible in various directions would enable us to

[1] *Outlines of Astronomy*, Tenth Edition, para. 785, 786.

determine the exact form of the stellar stratum, and also the position of the observer in the interior of the disc. For, as the volumes of spheres vary as the cubes of their radii, the number of stars visible in any two directions would be proportional to the cubes of the distances to which the stratum extends in the two directions. For instance, if in the field of view of the observing telescope 10 stars are counted in one direction and 80 in another, the length of the visual rays will be as 1 to 2, or as the cube roots of 1 to 8. From the observed numbers and a comparison between the area of the field of the observing telescope and the total area of the star sphere the length of the visual ray compared with the mean distance of stars of the first magnitude may also be computed (see Appendix, Note L).

In pursuance of the method above described, Sir W. Herschel undertook a series of "gauges," or counts of stars, visible in different portions of the heavens, with a reflecting telescope of 18·8 inches aperture. The magnifying power used was 157, and the diameter of the field of view about 15 minutes, 4 seconds of arc, or about half the Moon's apparent diameter.

It may be easily shown that the area of this field of view was equal to that of the whole celestial sphere divided by 833,000. It would therefore be necessary to count this immense number of fields in order to "gauge" the whole visible heavens.

Herschel's gauges number about 3400, so that in reality he examined only a small fraction of the celestial vault. The number of stars visible in these gauges range from 0 to 588. This latter number, large as it is for so small a field of view, would give for the whole heavens, if equally

rich, a total of 489,804,000 stars,[1] a number which, although absolutely large, must be considered as comparatively small, if we consider space as infinite in extent.

Herschel's gauges were, however, made along a great circle of the celestial sphere at right angles to the course of the Milky Way. This section is inclined at an angle of 35° to the Celestial Equator, which it cuts at 304½°, and 124½° of Right Ascension. It intersects the Milky Way at right angles, and passes close to the Galactic Poles. On one side of the star sphere it cuts the Milky Way in the two branches in Aquila, and at the opposite side in the southern portion of Monoceros, near Canis Major.

The section passes through the constellations Aquila, Aquarius, Piscis Australis, Cetus, Eridanus, Lepus, Monoceros, Hydra, Leo, Coma Berenices, Canes Venatici, Boötes, Corona Borealis, and Hercules.

The general form of the section of the stellar stratum as originally found by Herschel is shown in the accompanying diagram (Plate XV.), which I have carefully drawn to scale from the extensions deduced by Herschel from his observations.

He found the greatest diameter of the figure to have an extension of 850 times the mean distance of stars of the first magnitude; the thickness at right angles to the diameter of the disc, or in the direction of the poles of the Milky Way, being 155 of the same units. The Sun is not quite centrally placed either in the direction of the thickness or in that of the diameter of the disc.

[1] This fact has an important bearing on the question of a Limited Universe, a subject which will be considered in the concluding chapter of the present volume.

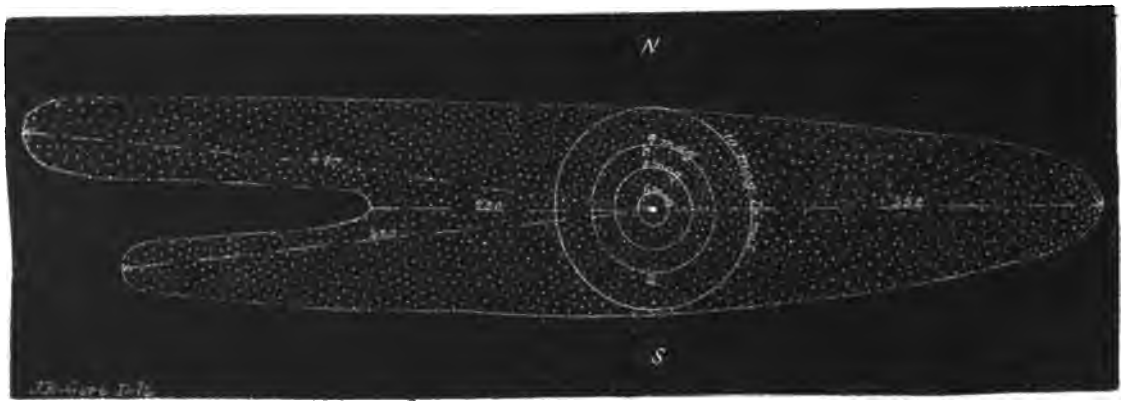

Plate XV.

Section of Sir W. Herschel's Stellar Disc,

Drawn to scale.

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In the direction of the thickness he found an extension of 75 units towards Coma Berenices, or Northern Galactic Pole, and 80 units towards Cetus, or the Southern Pole. In the direction of the diameter the maximum extension is in the direction of Aquila, where we have distances of 497 and 420 units. Between these two branches lies a void gulf of which the nearest point to the Sun is at a distance of 220 units.

In the opposite direction the extreme distance of the borders of the disc is at 352 of the same units, in that portion of the Milky Way above Canis Major. In the diagram the small circle in the centre includes all the stars visible to the naked eye to the sixth magnitude, the distance of which Herschel estimates at 12 times the average distance of stars of the first magnitude.[1]

Outside this small circle I have drawn another which includes all stars to the eighth magnitude inclusive. With a light ratio of 2·512, the radius of this circle will be 30·14 units of the adopted scale. A third circle shows the limit of stars of the ninth magnitude. The radius of this circle, with the assumed light ratio, would be 3·98 times that of stars of the sixth magnitude, or 47·76 units of the same scale. A fourth circle shows the limit of stars of the tenth magnitude. The radius of this circle would be 75·72 units. From this it appears that a telescope which shows stars to the tenth magnitude only should be sufficient to pierce through the thickness of the stellar disc in the direction of the North Galactic Pole.

[1] With a light ratio of 2·512, the value now generally adopted, the distance of a sixth-magnitude star should be ten times that of a first magnitude, but I have thought it better to retain Herschel's estimate.

As this is probably *not* the case it would seem that Herschel's assumed dimensions are too small. Assuming his dimensions, however, let us consider how the "disc theory" agrees with observation. As I have shown in the chapter on the Milky Way, the stars visible to the naked eye show a marked tendency to aggregation on the Galactic stream. Now as the average naked eye cannot penetrate beyond the small central circle in the diagram, we should find the number of naked-eye stars nearly the same in all directions, with of course a nebulous light in the direction of the Milky Way.

It may, however, be objected to this argument that the tendency of the lucid stars to crowd on the Milky Way is not sufficiently well marked to warrant us in drawing any decided conclusion from their apparent distribution over the celestial vault. Let us therefore consider the observed distribution of stars to the eighth and ninth magnitudes, of which the limiting circles fall well within the thickness of the hypothetical disc. Struve found[1] that for the hours vi. and i. of Right Ascension the ratio of stellar density is about 3 to 1 for stars down to the ninth magnitude in a zone extending from + 15° to − 15°. Argelander's maps show that for a distance of 30° on each side of the centre line of the Galactic Zone, the stars to the eighth magnitude inside these limits are more numerous than those outside in the ratio of about 2 to 1. For stars of the ninth magnitude this ratio is nearly 2½ to 1.

Adopting Struve's method of counting the stars in a zone from + 15° to − 15°, I have made a careful enumeration of the stars to the eighth magnitude inclusive as shown

[1] See Chapter XVI.

on Harding's charts, which are fairly complete for stars of that magnitude, at least in the selected zone.

The results I have found are given in the Appendix (Note M).

From this table it will be seen that the *absolute* maximum occurs in the hour xviii. to xix. (Milky Way), where the number of stars in the zone is 611, and the *absolute* minimum in hour i. to ii., where the number is 275. This gives a ratio of 2·22 to 1. Another maximum occurs in hour vi. to vii. (Milky Way), where the number is 601, and there is another minimum in hour xiii. to xiv. The maxima north of the Equator are found in hour xviii. to xix. (340), and hour vi. to vii. (329), both of which are crossed by the Milky Way. South of the Equator we have maxima at hours xx. to xxi. and vi. to vii.

The average for the whole zone is about 436 stars per hour of R. A.; the average for the hours v. to viii. being 543, and for the hours xviii. to xxi. 581 stars.

We see therefore that the stars down to only the eighth magnitude show a strongly marked tendency to aggregation on the Milky Way stream.

An examination of the diagram will show that these results are quite inconsistent with the disc theory of the Milky Way. As the stars are by hypothesis supposed to be uniformly distributed throughout every part of the disc, and as the limiting circles for stars to the eighth and ninth magnitudes fall well within the thickness of the disc, there is no reason why stars of these magnitudes should not be quite as numerous in the direction of the Galactic Poles as in that of the Milky Way itself. We see therefore that the disc theory fails to represent the observed facts, and

that Struve and Proctor were amply justified in their opinion that the theory is wholly untenable and should be abandoned.[1] These views are of course strengthened by the fact that the disc theory was abandoned by Herschel himself in his later writings.[2] As, however, this subject will be further discussed presently let us proceed with the consideration of Herschel's researches.

In his paper of 1785 Herschel suggests that some of the nebulæ may be external galaxies, possibly of dimensions far greater than our own. These are the nebulæ of large apparent size. He mentions ten, and includes among them the great nebulæ in Orion and Andromeda. He considered that the nebula in Andromeda was the nearest to our system, and its distance he estimates at 2000 times the distance of stars of the first magnitude. Modern observations, however, do not afford much evidence in favour of this hypothesis. The spectroscope shows the great nebula in Orion to be composed of incandescent gas, but of course this great instrument of research was unknown in Herschel's time. To the larger nebulæ he adds the planetary nebulæ as probably separate galaxies, placed at a vast distance from our system, but here again the spectroscope fails to confirm the hypothesis, most of these objects consisting of nothing but glowing gas.

Herschel's original disc theory was based on two assumptions, and would of course be mathematically true were these assumptions exactly or even approximately correct. These

[1] See Chapters XVI. and XVII.

[2] The demonstration of Herschel's change of views is sometimes ascribed to Proctor, but Struve arrived at exactly the same conclusion so far back as 1847 in his *Études d'Astronomie Stellaire* (see Chapter XVI.).

assumptions were, (1) that the distribution of the stars in space is uniform, or nearly so, and (2) that his gauging telescope was sufficiently powerful to reach everywhere, and beyond, the limits of the stellar stratum. In his memoir of 1785, Herschel says, with reference to the limits of the stratum, "It is true, that it would not be consistent confidently to affirm that we were on an island unless we had actually found ourselves everywhere bounded by the ocean"; and with reference to the power of his telescope he says, "From these considerations it appears again highly probable that my present telescope, not showing such a nebulosity in the Milky Way, goes already far beyond its extent." This latter conclusion he seems to have subsequently abandoned, at least in its *universal* application; and he entirely abandoned the assumption of an equal distribution of stars in his later writings.

Between 1785 and 1818 there are 12 of Herschel's papers which have a bearing on the construction of the Milky Way. (For a list of these papers see Appendix, Note N.) His views on the subject appear to have changed *gradually*. Even in 1799 he seems to still adhere to the original theory. For, in his paper on the penetrating power of telescopes, published in that year, he shows the agreement between the extreme extensions of the Milky Way found from the gauges and those derived from the penetration of his telescopes. In 1802, however, his views seem to have been wholly changed. He says:—

"For though our Sun, and all the stars we see, may truly be said to be in the plane of the Milky Way, yet I am now convinced by a long inspection and continued examination of it that the Milky Way itself consists of stars very differently scattered from those which are

immediately about us.' . . . "On a very slight examination it will appear that this immense starry aggregation is by no means uniform. The stars of which it is composed are very unequally scattered, and show evident marks of clustering together into many separate allotments."

And in the paper of 1811 he says :—

"I must freely confess that by continuing my sweeps of the heavens my opinion of the arrangement of the stars and their magnitudes, and some other particulars, has undergone a gradual change; and, indeed, when the novelty of the subject is considered, we cannot be surprised that many things formerly taken for granted should on examination prove to be different from what they were generally but incautiously supposed to be. For instance, an equal scattering of the stars may be admitted in certain calculations; but when we examine the Milky Way, or the closely compressed clusters of stars, of which my catalogues have recorded so many instances, this supposed equality of scattering must be given up. We may also have surmised nebulæ to be no other than clusters of stars disguised by their very great distance; but a longer experience and a better acquaintance with the nature of nebulæ will not allow a general admission of such a principle, although undoubtedly a cluster of stars may assume a nebulous appearance when it is too remote for us to discern the stars of which it is composed."

In his paper of 1817 Herschel expresses the opinion that although a large number of stars visible in the field of the telescope would generally indicate a great extension of stars in the line of sight, these gauges in reality point more directly to the relative condensation of the stars in space, and show the varying richness of star distribution in different regions of the sky. Here we have the first of the fundamental assumptions above referred to abandoned by the author himself.

With reference to Herschel's second fundamental assumption, namely, that his telescope was sufficiently powerful to

read the utmost limits of the Galactic Zone, and even to penetrate beyond its boundaries, this was also abandoned by the illustrious astronomer himself, as will be seen by the following facts. In his paper of 1817 Herschel mentions six gauges in which he had failed to resolve the Milky Way into stars, even when his telescope was improved by dispensing with the small mirror, and using the "front view." Even with his great 40-feet telescope he found cases in which the resolution into stars was uncertain, and he finally came to the conclusion—in the paper of 1818—that some portions at least of the Galaxy were beyond the powers of his telescopes. These telescopes were, however, only metallic mirrors, in which there is a considerable loss of light, owing to the imperfection of the reflecting surface. Herschel's failure therefore to resolve some portions of the Milky Way into stars cannot be considered surprising, and the result he arrived at, namely, that portions of the Galaxy are really unfathomable, cannot be accepted as final.

It is clear, however, that Herschel abandoned his second assumption as well as his first; and as the accuracy of the disc theory depends solely on these two assumptions, it is obvious that it has no ground to rest upon, and must therefore be finally rejected.

Another fact which militates against the disc theory has recently been discovered. Professor Pickering finds that most of the stars in the Milky Way show a spectrum of the first or Sirian type, which seems to indicate that the Galaxy forms a system *separate* from the remainder of the sidereal universe. If this be so, the disc theory of the visible heavens becomes at once untenable.

Let us now consider Herschel's further researches in stellar astronomy. His discovery of binary or revolving double stars in the year 1802 seems to have finally changed his views on the construction of the sidereal heavens. Here was evidence that, in some cases at least, stars might have a physical and not merely an optical connection, and that it would be no longer safe to conclude that two stars which differ greatly in brilliancy also differ widely in their distance from the earth.

Herschel extended the analogy of the double stars to multiple stars, and even to nebulæ, and to certain stars with surrounding nebulosity. He considered that there were isolated stars in space, and that our Sun was a star of this class. These isolated stars he supposed to be accompanied by planets and satellites, similar to our own Solar System. The observed "proper motions" of stars he thought more probably due to perturbations produced by their mutual attractions rather than a general revolution of the whole sidereal system round a common centre.

With reference to the Milky Way he considered that it showed everywhere a tendency to concentration into "clustering collections," and that this concentration increased with the increase in intensity of its brightness.

In his paper of 1811 Herschel develops his ideas on the formation of stars by condensation from nebulous matter, views somewhat similar to those advanced by Kant, and by Laplace in his famous Nebular Hypothesis.

In the memoir of 1814 he considers the clusters, and finds that those situated in rich portions of the sky are generally of an irregular form and not very concentrated. Those which are in or near the Milky Way he thinks form

portions of the Galaxy, which have been aggregated by the "clustering power." Of 233 clusters he finds that 146 are in the Milky Way, 63 near that zone, and 24 at a distance from the Galaxy. All these differ wholly from the globular clusters which he justly considers as the most interesting objects in the sidereal system. Of 30 globular clusters he found 11 in the Milky Way, 6 near it, and 14 at a distance from the Galactic Zone, from which it appears that the irregular clusters are more numerous in the Milky Way than those of a globular form. Out of a total of 263 clusters we have therefore 226 in or near the Milky Way, and 38 outside. Assuming an average width of 10 degrees for the Galactic Zone, its area will be about one-eleventh of the whole celestial sphere, and one-ninth of the part of the sky examined by Herschel. From this it is evident that clusters of stars are much more abundant in the Milky Way than in the other portions of the sky.

In his later writings Herschel considered the Milky Way as formed of an immense collection of star clusters irregularly condensed, the brighter portions being those visible to the naked eye, and he mentions 18 remarkable spots of nebulous light in the paper of 1817.

From a photometric consideration of the light of a number of stars from Sirius, Capella, and Vega down to stars of the sixth magnitude, he concludes that these latter are at 12 times the distance of stars of the first magnitude. Modern researches do not, however, confirm this conclusion, as some small stars—for instance, 61 Cygni—have been found to be actually nearer to the earth than Capella and Vega.

Herschel estimates that his 20-feet telescope penetrated

61 times farther into space than stars of the sixth magnitude, and with the "front view" 75 times. For his great 40-feet telescope he found a penetration of 195 times the distance of a sixth-magnitude star (see Appendix, Note O). Herschel thought that the brilliancy of the stars in Orion implied that the Milky Way in this vicinity was relatively near our system. This seems a plausible hypothesis enough, but modern observations for parallax do not lend much support to the view.

Considering the evidently great extension of the sidereal system even in the direction of the Galactic Poles, Herschel came to the conclusion that not only our Sun and Solar System, but all the stars visible to the naked eye are deeply immersed in the Milky Way stratum, and form part and parcel of that great system. On the disc theory this would obviously be the case, but if we reject this theory—as we seem bound to do—then our Solar System may be merely situated in or near the general plane of the vast ring which possibly forms the Galaxy.

The last of Herschel's memoirs, published in 1818, refers to the penetrating powers of his telescopes as a test for the distance of star clusters. This principle of estimating stellar distances Proctor argues is unsound, and his objections to Herschel's conclusions will be considered in Chapter XVII.

CHAPTER XV.

PROGRESS OF STELLAR ASTRONOMY FROM HERSCHEL TO STRUVE.

SIR WILLIAM HERSCHEL'S views on the construction of the Sun as an opaque body surrounded by a shining envelope arranged in layers seems to have been accepted by his immediate successors, but this theory does not now find favour among astronomers. According to Sir William Thomson, Helmholtz's theory of the solar heat compels us to consider that the Sun's mass must be in a fluid state from the surface to the centre (see chapter on "The Fuel of the Sun"). The idea of a solid opaque nucleus must therefore be abandoned.

Several valuable atlases and star charts have appeared since Herschel's time, notably that of Argelander, which contains 324,198 stars visible with a small telescope in the Northern Hemisphere.

With reference to the distances of the fixed stars Herschel's researches led to no result. In Herschel's time micrometers were not sufficiently perfect for such delicate investigations. Some stellar distances were, however, determined with considerable accuracy by Bessel, Peters, and Struve. The latter computes that the faintest stars visible in Herschel's 20-feet telescope lie at a distance from our system which light would take 3541 years to traverse!

Herschel's opinion that the Solar System is moving through space in the direction of the constellation Hercules has been fully confirmed by subsequent investigations. Argelander placed the reality of this solar motion beyond doubt by a comparison of the places of a large number of stars determined at Abo with those found by Bradley in 1755. The accuracy of Argelander's result was confirmed by Otto Struve, who also estimated the angular velocity of the Solar System as seen from the average distance of stars of the first magnitude. According to the elder Struve the following is the result arrived at by MM. Argelander, O. Struve, and Peters :—

"The motion of the Solar System in space is directed towards a point of the celestial vault situated on a right line which joins the two stars, of the 3rd magnitude, π and μ Herculis, at a quarter of the apparent distance of these stars from π Herculis. The velocity of the motion is such that the Sun, with all the bodies which depend on it, advances annually in the direction indicated 1·623 times the radius of the terrestrial orbit, or 33,550,000 miles geographical. The probable error of this last number rises to 4,733,000 miles geographical, or a seventh of the value found. We can therefore wager 400,000 to 1 on the reality of the progressive motion of the Sun, and 1 to 1 that it is comprised between 38 and 29 millions of miles geographical."[1]

The *general* accuracy of this conclusion has been verified by modern researches on the subject, although the separate determinations of the exact point towards which the Sun is moving differ to some extent, and the velocity of the motion is now believed to be considerably greater than that stated by Struve.

Bessel also made some researches on the subject, and detected irregularities in the proper motions of Sirius and

[1] *Études d'Astronomie Stellaire*, p. 108.

Procyon, which he ascribed to the attraction of an invisible disturbing body revolving in an orbit round the bright star. This conclusion has been partially verified by the discovery, in 1862, of a faint companion to Sirius, with which it forms a binary pair; but in the case of Procyon the disturbing body, if it exists, has not yet been detected. The subject of stellar proper motions has also been considered by Mädler, who came to the conclusion that the Pleiades formed the central group of the Milky Way system, and its principal star Alcyone the central sun, round which all the visible stars revolve, with the same mean angular velocity. This opinion has not, however, been accepted by modern astronomers, and was rejected in 1847 by Struve, who considered such an hypothesis "much too hazardous" in the present state of astronomical science.

In the department of double and multiple stars much progress has been made since Herschel's time, and the orbits of a considerable number of binary systems have been computed—some with a considerable approach to accuracy. Numerous measures of these most interesting objects were made at Dorpat and Poulkova in Russia, and Sir John Herschel during his residence at the Cape of Good Hope in the years 1834—1838 extended the research into the Southern Hemisphere and added largely to the number of double stars now known to exist.

Sir John Herschel also discovered a large number of new nebulæ, both in the Northern and Southern Hemispheres. Over 600 of these objects were also discovered at Paramatta by Dunlop, who seems to have first given, in 1827, a correct description of the so-called "Magellanic Clouds."

Sir John Herschel also carried out a series of "gauges"

in the Southern Hemisphere, similar to those observed by his illustrious father north of the Equator, and arrived at very similar results. His gauges number about 2300, and "show a gradual but rapid increase of density on either side of the Milky Way as we approach its course, and the reproduction of nearly the same law of graduation on the north side which holds good on the south, so far as the comparative paucity of the gauges taken in that direction allow us to judge."[1] From a consideration of these gauges he arrives at the following conclusions :—

"1st, That the larger stars are really nearer to us (taken *en masse*, and without denying individual exceptions) than the smaller ones. Were this not the case, were there really among the infinite multitude of stars, constituting the remoter portions of the Galaxy, numerous individuals of extravagant size and brightness, as compared with the generality of those around them, so as to overcome the effect of distance and appear to us as large stars, the probability of their occurrence in any given region would increase with the total apparent density of stars in that region, and would result in a preponderance of considerable stars in the Milky Way, beyond what the heavens really present, over its whole circumference. 2ndly, That the depth at which our system is plunged in the sidereal stratum constituting the Galaxy, reckoning from the southern surface or limit of that stratum, is about equal to that distance which on a general average corresponds to the light of a star of the 9th or 10th magnitude, and certainly does not exceed that corresponding to the 11th."[2]

Sir John Herschel, in speaking of "the sidereal stratum constituting the Galaxy," seems to accept the "disc theory" of the Milky Way. Having, however, made a careful telescopic examination of the Galaxy in Scorpio,

[1] *Cape Observations*, p. 380.

[2] *Ibid.*, p. 383. See also diagram in the preceding chapter of this volume.

Sagittarius, and Ophiuchus (see chapter on the Milky Way) he says :—

"From the foregoing analysis of the telescopic aspect of the Milky Way in this interesting region, I think it can hardly be doubted that it consists of portions differing exceedingly in distance, but brought by the effect of projection into the same or nearly the same visual line: in particular, that at the anterior edge of what we have called the main stream, we see, foreshortened, a vast and illimitable area scattered over with discontinuous masses and aggregates of stars in the manner of the cumuli of a mackerel sky, *rather than of a stratum of regular thickness and homogeneous formation.*"[1]

A conclusion evidently quite inconsistent with the "disc" theory.

With reference to the structure of the Milky Way and the theory of its constitution little more seems to have been done till the year 1847, when the elder Struve took up the subject and propounded his theory of the Milky Way, which will be considered in the following chapter.

[1] *Cape Observations*, p. 389. The italics are mine.

CHAPTER XVI.

STRUVE'S THEORY.

"Nous parvenons donc au resultat peut-être inattendu, mais incontestable, que le système de Herschel, énoncé en 1785, sur l'arrangement de la voie lactée, s'écroule de toutes partes, d'après les recherches ultérieures de l'auteur; et que Herschel lui-même l'a entièrement abandonné."[1]—STRUVE.

FROM a careful study and discussion of Sir William Herschel's papers, the famous astronomer, F. G. W. Struve arrived at the conclusion contained in the quotation at the head of this chapter. He further says: "Quant à l'explication de la voie lactée, la science est restée a peu près stationnaire, depuis de décès de Sir W. Herschel. Mais on peut demander, pourquoi les astronomes ont-ils maintenu généralement l'ancien système sur la voie lactée, énoncé en 1785, quoiqu'il eût été entièrement abandonné par l'auteur lui-même, comme nous l'avons démontré. Je crois qu'il faut en chercher l'explication dans deux circonstances. C'était un système entier, imposant par la hardiesse et la précision géométrique de sa construction, et que l'auteur n'avait jamais révoqué dans sa totalité. Dans ses traités, publiés depuis 1802, on ne rencontre que des vues partielles, mais qui suffisent, en les comparant entres elles, à comprendre l'idée finale du grand astronome."[2]

[1] *Études d'Astronomie Stellaire*, p. 34. [2] *Ibid.*, pp. 49, 50.

These opinions, published in 1847 and emanating from so distinguished an astronomer as Struve, have, however, not prevented Herschel's original "disc" theory of the Milky Way from maintaining its ground in most popular works on astronomy. Struve's views on the subject are, it seems to me, undoubtedly correct; but in seeking to surmount the difficulties surrounding the disc theory he has, I think, in avoiding Scylla encountered Charybdis, and in attempting to improve upon the original theory he has himself advanced an hypothesis which is equally untenable.

An account of Struve's researches on the subject may, however, prove of interest to the reader. They are very elaborately worked out, and are contained in his interesting and still valuable work *Études d'Astronomie Stellaire—sur la Voie Lactée, et sur la Distance des Étoiles Fixes*, published at St. Petersburgh in 1847.

In his *Description de l'Observatoire central*,[1] pp. 268-71, Struve expressed some views on the constitution of the Milky Way founded on a consideration of the distribution of stars down to the seventh magnitude in the Northern Hemisphere. Thinking, however, that these data were very inadequate for the purpose he again took up the research, on the publication of a catalogue calculated by M. Weisse from Bessel's zone observations. These zones extend from 15° north of the Equator to 15° south,[2] and contain the

[1] Poulkova (*Nicolai-Hauptsternwarte Pulkowa*), near St. Petersburgh.

[2] "*Positiones mediæ stellarum fixarum in zonis Regiomontanis a Besselio inter −15° et +15° declinationis observatorum, ad annum* 1825 *reductæ et in catalogum ordinatæ, auctore M. Weisse. Jussu Academiæ Imperialis Petropolitanæ edi curavit et præfatus est F. G. W. Struve. Petropoli* 1846, 4to."

positions of 31,895 stars, of which the majority were observed only once.

There are, however, 4776 stars observed on two or more occasions, and 807 stars lying outside the limits of the catalogue. Rejecting these, and also 3 stars of the tenth magnitude, there remain 31,085 stars to the ninth magnitude, included in a zone of 30° width in declination, the Equator forming the central line of the zone. Classified according to brightness there are 664 stars of magnitudes 1 to 6; 2500 stars of seventh magnitude, 8183 of eighth magnitude, and 19,738 of the ninth magnitude. Struve, however, thinks that these numbers should be greater, and comparing the catalogue with Argelander's *Uranometria* he finds that of 1014 stars seen by Argelander the catalogue only contains 825, or 81 per cent., which gives the number 39,146 as that which *should* be contained in Weisse's Catalogue.

Considering this number as still uncertain, owing to the probability of stars being missed in the illuminated field of the telescope, he examined the catalogue of Piazzi, which contains 7646 stars, of which 2502 belong to his selected zone. Comparing the number of stars to the eighth magnitude contained in *both* catalogues, and with due regard to differences in the notation of brightness of the two observers, he finds Weisse's number 82·09 per cent. of Piazzi's number, in close agreement with the percentage of 81·36 found by comparison with Argelander's *Uranometria* for stars of 1 to 6 magnitude. This ratio is, however, not constant for all hours of Right Ascension, being greatest for those hours, such as xii., which are poor in stars, and smallest in the richest, such as hour vi. For the former we have a percentage of 91·74, and for the latter 56·87.

Abandoning, therefore, the method of comparing the catalogues for the entire zone, he adopts a method of estimating the number of stars of each magnitude per hour of Right Ascension, and arrives at the conclusion that the zone contains 14,460 stars of magnitudes 1 to 8, of which 11,347 were observed by Bessel, giving a mean percentage of 78·47. To obtain an estimate of the number of stars of the ninth magnitude, Struve has recourse to the calculus of probabilities, deriving his data from a consideration of the number of stars observed more than once in Bessel's zones. In this way he finds the probable number of ninth-magnitude stars to be 37,739, and therefore the total number to the ninth magnitude inclusive in the selected zone as 52,199 (giving a mean percentage for Bessel's Catalogue of 59·55).

Discussing then the number of stars in each hour of Right Ascension he finds that the numbers increase from hour i. to hour vi., where they attain a maximum. They then diminish to a minimum at hour xiii., and rise to another but smaller maximum at hour xviii., again decreasing to a second minimum at hour xxii. As the hours vi. and xviii. are those crossed by the Milky Way, the result is very significant. Struve divides the total zone into six regions, each of four hours, two being rich in stars and four poor. The two rich regions include the hours v. to viii., and xvii. to xx. The relative richness may be well seen by considering that out of 37,739 stars of ninth magnitude—which gives a mean of 1572 stars per hour—hour i. contains 1084 and hour vi. 3318. These numbers divided by 1572 give 0·689 and 2·110, numbers which express the relative density of these hours compared to the mean

density of the zone (or a relative density for the hours i. to vi. of 1 to 3·06).

Assuming as unity the radius of the sphere which contains all the stars visible to the naked eye (to sixth magnitude inclusive) according to Argelander, Struve computes the radii of the spheres containing stars to the fifth magnitude of Argelander, and to the seventh, eighth, and ninth magnitudes of Bessel, and finds the numbers 0·7126, 1·6113, 2·5560, and 3·9350 respectively. The subject of his research is then a portion of a sphere—on both sides of the celestial Equator—bounded by two conical surfaces inclined 15° to the Equator, the apex being situated in the Sun, and the radius of the sphere nearly four times the extreme distance of the stars visible to the naked eye.[1]

Struve then proceeds to make the hazardous assumption that the stars contained in his zone may be supposed collected on the Equator into an equatorial disc of indeterminate thickness. He says: "En considérant maintenant que nous avons fait abstraction des déclinations, dans notre recherche sur la distribution des étoiles, les chiffres obtenus des densités peuvent être regardés comme valables, pour un disque équatorial, d'une épaisseur indéterminée, et dont le rayon est égal à celui de la sphère totale."

From an examination of a graphical representation of this imaginary equatorial disc he arrives at the following conclusions:—

1. The Sun occupies the centre of the disc, and is sur-

[1] With a "light ratio" of 2·512 (of which log = 0·4) we have light of a sixth-magnitude star = $(2{\cdot}512)^3$ × light of ninth-magnitude star, and therefore distance of ninth-magnitude star (distance of sixth magnitude = 1) = $(2{\cdot}512)^{\frac{3}{2}}$ = 3·9813, which agrees closely with Struve's result computed on a different principle.

rounded on all sides by stars of nine classes of magnitude; but there is a remarkable condensation in the distribution of the stars, nearly towards a principal diameter of the disc lying between R. A. 6h. 40m. and 18h. 40m. of its circumference.

2. The minimum densities lie on the diameter from R. A. 1h. 30m. to 13h. 30m.

3. He assumes that the law of condensation is such that, dividing the disc into bands parallel to the principal diameter, the density in each successive band diminishes on both sides of this diameter, and in proportion to its distance from the diameter. His words are: "Nous ne pouvons admettre, pour la condensation, d'autre loi que celle, qu'en divisant le disque en bandes parallèles au diamètre principal, la densité dans ces bandes successives diminue, les deux côtes du diamètre principal, avec la distance à ce diamètre." Comparing, for stars of the ninth magnitude, the mean 1·751 of the greatest densities, in the hours vi. and xviii., with the mean 0·686 of the two smallest densities, in the hours i. and xiii., we obtain the fraction $\frac{0\cdot686}{1\cdot751} = 0\cdot392$ for the density of a band which is at a distance from the principal diameter of 3·415 times that of stars of the sixth magnitude.

4. The regularity of stellar distribution parallel to the principal plane is well shown by the fact that any semicircle of the disc contains approximately the same number of stars, whatever be the position of the dividing diameter.

5. The appearance of the disc shows that the line of maximum density does not pass exactly through the Sun. If this line be bisected, the Sun is situated at a distance

from the point of bisection equal to about one-tenth of the distance of stars of the sixth magnitude, and in the direction of R. A. 12h. 40m. The effect of this small eccentricity in the Sun's position is also shown by the distribution of the naked-eye stars, for which the points of maximum density lie in R. A. 5h. 30m. and 20h. 30m., the mean of which, or 13h. 0m., gives the direction in which the Sun is placed, and its distance from the principal diameter equal to 0·19 of the distance of stars of the sixth magnitude. Taking a mean of the two determinations Struve concludes that the Sun lies towards 12h. 50m., or towards the constellation Virgo, and that its distance from the principal diameter is about 0·15 of that of stars of the sixth magnitude, a distance about equal to the radius of the sphere which separates stars of the first and second magnitude.

6. The line of maximum density is, however, not exactly a straight line, but shows inflexions (or curves), and in its vicinity remarkable vacuities and aggregations in stellar density. Thus in the direction of Orion there is a notable richness of lucid stars, while towards Serpentarius the naked-eye stars are comparatively few. Small anomalies are also apparent in the fainter classes of star magnitudes, and possibly these anomalies may explain the fact that the angle between the diameters of maximum and minimum density is 78° instead of 90°.

Having arrived at these conclusions from a consideration of his supposed disc, Struve proceeds to compare his results with the actual phenomena of the Milky Way. He says that the Galaxy does not exactly form a great circle of the celestial sphere, but that its mean centre line is distant nearly 92° from its Northern Pole, which lies near the

borders of Coma Berenices and Canes Venatici ; the celestial Equator being intersected in R. A. 18h. 36m. near the tail of Serpentarius, at an angle of about 55°, this being the ascending node ; and at the opposite point, which is the descending node, in R. A. 6h. 40m. at an angle of 60°·6. The Milky Way attains its maximum Northern Declination —about 53°·5—in Cassiopeia in R. A. 0h. 40m., and its maximum Southern Declination—about 63°—in the Cross in R. A. 12h. 40m.

In opposition to Struve's view Sir John Herschel expresses his opinion that the Milky Way *does* form a great circle of the sphere, and says : " M. Struve maintains the Galactic circle to be a small, not a great, circle of the sphere. The appeal is to the eyesight. I retain my own conviction."[1] Houzeau's researches—already referred to—show a deviation from a great circle of only 20′ of arc, and he concludes "qu'on peut evidemmedent regarder son cercle médian comme un grand cercle de la sphère." Dr. Gould says : " From the 48 positions thus obtained, without previous bias of judgement, for the medial line that curve was sought which should most nearly represent them as a whole. The result justifies the distinct statement that, excepting from 15½h. to 19½h. of right-ascension, where the branches are separated, the medial line of the Galaxy is not distinguishable from a great circle."[2] Herr J. Plassmann says : " Bei all ihrer Unregelmassigkeit schmeigt doch die Milchstrasse sich einem grossten kreise ziemlich gut an."[3]

[1] *Outlines of Astronomy*, Tenth Edition, p. 575, footnote.

[2] *Uranometria Argentina*, p. 370.

[3] *Über Grösse Gestalt und Sternfülle der Milchstrasse*, referred to in Chapter IX.

With the opinions thus expressed by Gould, Sir John Herschel, Houzeau, and Plassmann I fully concur.

It should, however, be stated that Sir John Herschel's gauges in the Southern Hemisphere—"made with the same telescope, field of view, and magnifying power employed in Sir William Herschel's gauges"—seem to show a slight excess of stars in the Southern Galactic Hemisphere, which Sir John Herschel thinks "may, and not improbably does, arise, from our situation not being precisely in the middle of its thickness, but somewhat nearer to its northern surface."[1] This view was, however, based on the assumption of the "disc" theory, a theory which I believe to be quite untenable.

With reference to his general result Struve says: "Il est donc hors de doute que le phénomène de la condensation des étoiles, vers une ligne principale du disque équatorial, est le plus étroitement lié avec la nature de la voie lactée, ou plutôt, que cette condensation et l'aspect de la voie lactée sont des phénomènes identiques."[2]

In Struve's researches on his "equatorial disc" the bifurcation of the Milky Way in Aquila and Ophiuchus is not indicated. This he explains by the fact that his investigation of stellar distribution was not made in full detail, but by hours of Right Ascension, and also because the Milky Way stream is inclined to the Equator at an angle of about 60°.

Struve seems to have misunderstood the observations made by Sir W. Herschel with his 40-feet telescope. He says: "Herschel a prouvé, en 1817, que la voie lactée est

[1] *Outlines of Astronomy*, p. 578.
[2] *Etudes d'Astronomie Stellaire*, p. 62.

insondable, même pour son télescope de 40 pieds. La même incertitude, sur les limites des étoiles visibles, existe dans toutes les autres directions de la voûte céleste, donc aussi vers les pôles de la Voie. Nulle part nous ne sommes en état de distinguer les dernières étoiles. Il s'en suit, que si nous regardons toutes les étoiles fixes qui entourent le Soleil, comme formant un grand système, celui de la voie lactée, nous sommes en parfaite ignorance sur son étendue, et que nous n'avons pas le moindre idée sur la forme extérieure de cet immense systéme."[1] It seems more than doubtful, however, that any such construction can legitimately be put on Sir W. Herschel's observations. Only in certain directions did Herschel find the Milky Way unfathomable, and this, in all probability, was chiefly due to the inadequate power of his telescope. The fact that in Herschel's original theory the Galaxy was indicated by a disc, limited both in diameter as well as in thickness, shows clearly that he supposed the Milky Way—at least, in his earlier writings—to be *not* infinitely extended in the direction of its plane. Struve's view seems to be similar to that of Wright of Durham, who draws a disc of limited thickness but unlimited diameter.[2]

With reference to Struve's remark, "Nulle part nous ne sommes en état de distinguer les dernières étoiles"—even in the direction of the Galactic Poles—M. Celoria has recently found that with a telescope showing stars to only the eleventh magnitude, the number visible at the Northern Pole of the Milky Way was almost exactly the same as that shown by Herschel's great reflector, thus indicating that

[1] *Études d'Astronomie Stellaire*, p. 63.

[2] Wright's *Theory of the Universe*, Plate XXIII., p. 64.

the limits of the sidereal cluster have been reached in that direction.

In order to ascertain whether the law of stellar distribution for stars down to the ninth magnitude holds good for stars below that magnitude in brightness, Struve examined the gauges of Sir W. Herschel which fall in his selected zone (15° North to 15° South Declination). Out of 683 gauges there are 266 available for this purpose. He gives a table showing the mean number of stars visible in Herschel's telescopic field, in each hour of Right Ascension, from which it appears that the maximum (richness) of stellar density falls in the hours vi., vii., and xviii., xix., the absolute maximum being in hour xix., which yields 102 stars per field of 15′ 4″ in diameter, and the absolute minimum in hours xi. and xii., which show only 5 stars per field, the mean number for the whole 24 hours being about 27. Comparing these results with those afforded by his "equatorial disc," Struve arrives at the following conclusions :—

1. The maximum and minimum of stellar density fall nearly on the same points of the circumference.

2. The difference between the maximum and minimum density is, however, much more strongly marked in Herschel's gauges than in Struve's zone. The latter shows a proportion between maximum and minimum of 2·51 to 1, while the former gives the ratio of about 14·1 to 1. [From this it is evident that there is an increased condensation of fainter stars in the direction of the Milky Way. This may, however, possibly be due to the augmented number of *small*[1] stars

[1] That is, stars *really small in size*, and not merely faint owing to immensity of distance.

(rendered visible by the larger telescope) which produce the Milky Way light, and does not *necessarily* prove an increased extension in the direction of the Galactic plane.]

3. The minimum towards hour xii. agrees with the position of the Sun, deduced from the "equatorial disc."

The area of Struve's zone (+ 15° to −15°) is equal to 215,592 times that of the field of Herschel's telescope. This multiplied by the average number of stars in Herschel's gauges, 26·995, gives 5,819,000 stars in the zone.

With reference to some further researches on the construction of the Milky Way, Struve well says: "Ce phénomène est tellement énigmatique, au premier coup d'œil, qu'on est presque tenté de renoncer à une explication satisfaisante. Cependant l'homme de science ne doit jamais reculer, ni devant l'obscurité d'un phénomène, ni devant la difficulté d'une recherche. Qu'il se mette en possession des travaux anterieurs, qu'il tâche d'augmenter la connaissance du phénomène, par de nouvelles observations précises; et il pourra être sûr d'un certain succès de ses études, s'il emploie une spéculation calme, sans s'abandonner aux influences d'une fantaisie excitée et préoccupée. Quelque petit terrain qu'il ait gagné, il l'élargira toujours, en revenant sur son problème avec cette persistance qui est la condition indispensable de l'étude. C'est alors que, guidé par l'analyse et le calcul, il peut parvenir à des résultats même inattendus, et qui jouissent cependant d'une haute certitude."[1]

Considering the Milky Way as a cluster of extended but indeterminate form, Struve proceeds to determine the law of stellar condensation with reference to the distance of

[1] *Études d'Astronomie Stellaire*, p. 67.

any given point from the principal Galactic plane. This research is facilitated by the fact that the Sun's situation is comparatively close to the principal plane, distant from that plane—according to Struve's results—only $\frac{1}{250}$ of the radius of the sphere which contains all the stars visible in Herschel's 20-feet telescope. An enumeration of the stars to the eighth magnitude in the selected zone (+ 15° to − 15°) in opposite hours as i. and xiii., ii. and xiv., iii. and xv., etc., show an approximate approach to equality. A similar equality is shown in the hours not opposite but corresponding, that is, in those hours which are at the same distance from the hours of maximum density, vi. and xviii. (such as xxiii. and xi., xii.; xxii., and x., xiv., etc.). The latter show a remarkably regular increase from minimum to maximum.

Dividing the total number into two portions by the diameter from R. A. 6h. 30m. to 18h. 30m., he finds:—

In the 12 hours from 6h. 30m. to 18h. 30m., 7116 stars.
„ „ „ 18h. 30m. to 6h. 30m., 7344 „

The small excess of 228 stars in the second hemisphere is in agreement with the supposed position of the Sun towards hour xiii.

Considering the sum of the stars 1 to 9 magnitude, Struve finds that for the four poor regions of his zone—viz., hours i. to iv., ix. to xii., xiii. to xvi., and xxi. to 0—there is an approach to equality in the number of stars in each region, the mean being—for the groups of four hours each—6987 stars. For the two rich regions he finds:—

In the four hours v. to viii., 13,593 stars 1 to 9 mag.
„ „ xvii. to xx., 10,657 „ „

The difference of 2936 stars, if not due to inaccuracy in the date, would indicate a greater star density towards 6 hours than towards 18 hours.

Treating in the same way the results derived from Herschel's gauges he finds for the rich regions :—

In the hours v. to viii., 1,984,200 stars visible to Herschel
„ „ xvii. to xx. 2,365,100 „ „ „ „

which gives an excess of 380,900 stars towards 18 hours (a result in opposition to that found above for stars of 1 to 9 magnitude).

For the poor regions he finds :—

In the 8 hours ix. to xvi., 622,400 stars visible to Herschel
„ „ xxi. to iv., 847,300 „ „ „ „

which gives a surplus of 224,900 stars towards 0h.

The first excess suggests that the stellar condensation does not depend solely on the distance from the principal plane, but varies slightly *in* that plane. Owing, however, to the small portion of the celestial vault covered by Herschel's gauges the number of stars deduced from them by Struve—as existing in his zone—are of course open to considerable uncertainty. Struve notes[1] that the combined gauges (3400 in number) of Sir W. Herschel only cover $\frac{1}{250}$ of the whole celestial vault, and that the complete gauging of the sky is quite beyond the power of a single observer. In fact, if 100 gauges could be made each night on 100 nights per annum, it would take 83 years to complete the task. The introduction of photography has,

[1] *Études d'Astronomie Stellaire*, Note 74.

however, now removed this difficulty, and when the heavens have been completely charted in this way Struve's researches and calculations may perhaps be repeated with advantage. In the meantime an outline of Struve's method may prove of interest to the reader.

From a careful examination of the whole of Herschel's gauges, Struve finds the following mean results :—

Angular distance from middle line of Milky Way.	Mean number of stars per field visible in Herschel's telescope.				
0°	122·0	for	151	multiple	gauges.
15°	30·30	„	56	„	„
30°	17·68	„	34	„	„
45°	10·36	„	48	„	„
60°	6·52	„	18	„	„

The gauges in the vicinity of the Northern Galactic Pole are so few in number that the number of stars per field corresponding to the angular distances 75° and 90° cannot be determined with sufficient accuracy. For 75°, however, Struve finds the approximate number 4·68, and for 90° (or the Pole) 4·15 ; and he gives a formula for the calculation of the number corresponding to any angular distance from the Milky Way, and a table computed from this formula. With reference to this table Struve remarks that the most rapid change in the number of stars occurs at about 2° from the middle of the Milky Way, and that this seems to explain the fact that the width of the Galaxy, as visible to the naked eye, is comparatively small—about 4°.[1] From the above results it appears that Herschel's telescope

[1] The *average* width of the Milky Way stream is, however, considerably greater than this.

showed nearly thirty times as many stars in the middle of the Milky Way as it did near the Pole.

Struve then computes (by integration from the above results) the total number of stars which would be visible in Herschel's 20-feet telescope, and finds,

For the hemisphere . . . . 10,187,017 stars.
Therefore for the whole celestial vault 20,374,034 stars.[1]

He then proceeds to find an expression for the density of stars in space with reference to their linear distance from the Galactic plane. He says: "L'accord entre les sommes des étoiles qui sont visibles dans des directions, soit opposées, soit correspondantes par rapport au plan principal, nous a autorisés d'admettre, que l'espace divisé par des plans parallèles au plan principal a, dans chaque couche différentielle ainsi formée, une condensation uniforme, mais qui diminue avec l'eloignement entre la couche et le plan principal."[2]

It seems highly improbable that this hypothesis of condensation in parallel planes—a constitution somewhat similar to that of the earth's atmosphere—should represent the real law of stellar distribution. A glance at Dr. Boeddicker's drawing of the Milky Way will, I think, be sufficient to controvert any such assumption.

Let us, however, follow Struve in his calculations based on the above hypothesis. From an analytical investigation he deduces a formula for the stellar density in terms of

[1] Assuming that the *minimum visibile* of this telescope was 14¼ magnitude, the total number of stars which *should* be visible with such a telescope is, according to Gould's formula, 549,660,000 nearly.

[2] *Études d'Astronomie Stellaire*, pp. 72, 73.

powers of the linear distance from the principal plane of the Milky Way, taking as unity the radius of the sphere which contains all the stars visible in Herschel's telescope, and the density of the stars in the principal plane as unity.

From this table it appears that the stellar density decreases very rapidly. At a distance of only $\frac{1}{20}$ it is below a half, and at a distance of 0·866 it is reduced to $\frac{1}{100}$ of that in the plane of the Galaxy. At this latter distance the space between two neighbouring stars is, on Struve's hypothesis, about $5\frac{3}{4}$ times greater than in the principal plane. Struve says: "Aussi n'est-il point impossible que du côté du pôle, le télescope de Herschel ait touché à peu près à la limite extérieure du système. Pour decider cette question, il faudra examiner la region du pôle avec deux télescopes, dont l'un aurait la pénétration à peu près égale à celle du télescope de Herschel, et l'autre une pénétration plus grande. Si le nombre des étoiles visibles est le même, dans les deux instruments, la limite est trouvée dans cette direction." The correctness of this opinion is shown by M. Celoria's observation already referred to, and the question will doubtless be finally decided by photography.

By a further analysis Struve computes for an hour of R. A. of his zone (+ 15° to −15°) "le nombre d'étoiles que cette portion de la voûte présenterait, si elle était remplie dans sa totalité, par des étoiles condensées comme au milieu de la voie lactée," and finds the following results :—

1,095,920	stars of	magnitude	1 to Herschel's faintest.
4983	„	„	1 to 9 of Bessel.
1422	„	„	1 to 8 „
279	„	„	1 to 7 „

"The cube roots of these numbers express the relation between the radii of the four spheres," and give :—

	Radius of sphere which contains the stars.	
For Herschel's stars	1·0000	9·1684
„ 9 mag. of Bessel	0·16567	1·5189
„ 8 „ „	0·10907	1·0000
„ 7 „ „	0·06338	0·5811

Comparing these numbers with the corresponding densities from formulæ which he gives, and discussing the number of stars of the different classes in the *whole*[1] of the Northern Hemisphere, as shown in Argelander's *Uranometria*, Struve computes a table of relative distances of stars of different magnitudes (see Appendix, Note P).

From these results he draws the following conclusions :—

1. The faintest stars visible to the naked eye, according to Argelander, are placed at a distance of 8·8726 times the mean distance of stars of the first magnitude. [With the now generally accepted light ratio of 2·512 the light of a first-magnitude star would be a hundred times the light of a sixth magnitude, and hence the distance of a sixth-magnitude star would be ten times the distance of a first magnitude, supposing both stars to be of equal size and brightness.]

2. The faintest stars of ninth magnitude observed in Bessel's zones are at a distance of 37·73 times the distance of stars of first magnitude, or 4·25 times that of stars of sixth magnitude.

3. The faintest stars seen in Herschel's sweeps with the

[1] The number of stars 1 to 6 magnitude in the selected zone being inadequate for the purpose.

20-feet telescope are at a distance of 227·8 times the distance of stars of first magnitude, or 25·67 times that of sixth-magnitude stars.

With reference to the supposed position of the Sun—a little outside the principal Galactic plane—Struve finds for its distance from that plane a final value of 0·21 of the mean distance of stars of the first magnitude, and says: "Mais comment expliquer à présent la déviation de la voie lactée, de la forme du grand cercle? Voici ce que je pense. La couche la plus condensée des étoiles ne forme point un plan parfait, mais plutôt un plan brisé; ou bien, elle se trouve dans deux plans, inclinés l'un sur l'autre d'environ 10°, et dont l'intersection est placée à peu prés dans le plan de l'equateur céleste, le Soleil se trouvant à une petite distance de cette ligne d'intersection, vers le point 13h. de l'equateur."[1]

Struve then proceeds to discuss the bearing of his own researches on the hypothesis of the extinction of light in the ether of space. This idea of light extinction seems to have been first suggested by M. L. de Cheseaux in an article published at Geneva in the year 1744. In this work Cheseaux attempts to determine the distance of stars of the first magnitude by a comparison between their light and that of the planet Mars, observed in various parts of its orbit.

By this method he found a distance of 20,000 times[2] the Sun's distance from the earth, and the mean apparent diameter of a first-magnitude star equal to $\frac{1}{125}$th of a second. [Modern observations show that Cheseaux's distance is much too small, but his apparent stellar diameter is perhaps

[1] *Études d'Astronomie Stellaire*, p. 82.

[2] Corresponding to a parallax of about 10 seconds of arc.

not far from the truth.] Olbers, from a comparison of Mars and Aldebaran, found for the latter a distance of 344,643 times the Sun's distance from the earth, and from comparisons of Saturn and Procyon a distance for Procyon of 378,972 times the Sun's distance. [These distances, although much nearer the truth than Cheseaux's result, are still too small, as shown by more precise modern observations.] For stars of the sixth magnitude Olbers found, by comparison with the planet Uranus, a distance nearly ten times greater than stars of the first magnitude,[1] an estimate which agrees with that derived from the now generally accepted light ratio of 2·512.

In a paper published by Olbers in *Bode's Jahrbuch* for 1823[2] he refers to an error of Halley, who denied that an infinite number of stars would produce a sky as brilliant as the Sun. Olbers maintains that such would be the case, and in order the reconcile the appearance of the sky with the hypothesis of a stellar universe of infinite extent, he thinks it is necessary to admit an extinction of light in stellar space. He says: "Let us congratulate ourselves that nature has arranged the thing otherwise, and that each point of the celestial vault does not send solar light upon the earth. Without considering the insupportable brightness and exorbitant heat which would reign (for the Almighty Creator would have protected the earth and its organised beings against the action of this heat, even if it were 90,000 times greater than we experience at

[1] From photometric experiments Sir W. Herschel deduced a distance for stars of sixth magnitude twelve times greater than that of stars of first magnitude.

[2] *Ueber die Durchsichtigkeit des Weltrauns von H. Dr. Olbers*, dated 7th March, 1823.

present), I only wish to mention the astronomy, imperfect to the last degree, which would be within the range of the inhabitants of the earth. We should know nothing of the starry sky, we could with difficulty discover our Sun by its spots, and with difficulty distinguish the Moon and the planets by their darker discs on the dazzling ground of the sky. Is it necessary then to abandon the idea of an infinity of systems of fixed stars because the celestial vault does not shine with the brightness of the Sun? Is it necessary to restrict these worlds to an insignificant portion of infinite space? By no means."[1]

Sir W. Herschel estimated the "space penetrating power" of the telescope used in his gauges at 61·18—that is, that with the aid of this telescope he could see stars at 61·18 times the distance of the faintest stars visible to the naked eye. This estimate was based on the assumption that the diameter of the eye pupil was 0·2 inch. As, however, a telescope gives a sharper image of a star than that produced by the unassisted vision, Struve thinks that a comparison between the two cannot be strictly made. To remedy this defect he substituted for the eye a small telescope of 0·211 inch aperture, magnifying about three times. This little instrument, he considers, gives the same quantity of light and produces an image which is independent of the nature of the observer's eye, whether short-sighted or long-sighted. Using this "module" telescope Struve found by numerous experiments that he could see in all directions of the sky nearly double the number of stars shown in Argelander's maps, or more exactly, 183 stars to Argelander's 100.

[1] This quotation from Olbers' paper I have translated from the French of M. Struve.

He finds, then, for the sphere which contains all the stars visible with the module, a radius equal to 10·852 times the mean distance of stars of the first magnitude.[1]

Herschel found this radius equal to 12, a close agreement. He also found for the range of Herschel's telescope 74·83 times the distance of sixth-magnitude stars, and 74·83 × 8·8726 = 663·94 times the mean distance of stars of the first magnitude.

Now Struve's examination of Herschel's gauges gave for his faintest stars a distance equal to 25·672 times the mean distance of stars of the sixth magnitude, or a little more than one-third of the range due to its optical power. How is this difference to be explained?

Struve says: "Je ne vois point d'autre explication que celle d'admettre, que l'intensité de la lumière décroit en plus grande proportion que la raison inverse des carrés des distances ; ce qui veut dire qu'il existe une perte de lumière, une extinction, dans le passage de la lumière par l'espace céleste."[2]

Struve shows that, with a space-penetrating power of 74·83, the number of stars visible in Herschel's gauges should be 3021 instead of 122. He says: "Peut-être, dira-t-on, y a-t-il une diminution de densité dans le plan principal, vers les limites de la voie lactée.[3] Mais que savons-nous de ces limites? La voie lactée nous est absolument insondable. Quelle est donc la probabilité que le Soleil se trouve près du centre d'un disque, dont l'étendue nous est entièrement inconnue. Souvenons nous enfin, que

[1] See "Table of Relative Distances," Appendix, Note P.

[2] *Études d'Astronomie Stellaire*, p. 86.

[3] This is the most probable explanation.

l'examen des étoiles herschéliennes a conduit à la même loi moyenne du decroissement de densité dans le sens perpendiculaire au plan principal, qui a lieu dans le voisinage du Soleil, jusqu'à la distance des étoiles de 8-ème et 9-ème grandeur. Par toutes ces considérations, j'ose avancer que nous avons découvert un fait, dans lequel l'extinction de la lumière des étoiles s'est manifestée presque indubitablement."[1]

He then proceeds to determine the numerical value of this hypothetical extinction of light. Taking as unity the distance of stars of the sixth magnitude, and supposing that the light in passing over this unit of distance is reduced in intensity—by the absorption—from unity to a certain fraction, he computes from the theoretical range of Herschel's telescope, 74·83, and the actual range, 25·672 (deduced from an examination of Herschel's gauges), the value of this fraction. This he finds to be 0·92, and hence the loss of light is 0·08, or eight per cent. of the original intensity. From the Table of Relative Distances (see Appendix, Note P) we have the distance of sixth-magnitude stars = 8·8726 times that of stars of first magnitude. From this he computes the loss of light for stars of first magnitude, and finds it 0·009349, or $\frac{1}{107}$ of the original intensity.

Calculating a table for stars at different distances, he finds that the effect of the extinction of light, which for stars of first magnitude is only one per cent., and eight per cent. for stars of the sixth magnitude, increases to thirty per cent. for Bessel's ninth-magnitude stars, and to eighty-eight per cent. for the faintest stars visible in Herschel's gauging telescope. Beyond this distance the

[1] *Études d'Astronomie Stellaire*, p. 87.

diminution of light becomes very rapid, and for a distance equal to 1470·8 times the distance of stars of first magnitude the light would be reduced to $\frac{1}{100.000}$ of its original intensity!

This diminution of light would of course reduce the range of telescopes very considerably. For Herschel's 40-feet telescope the theoretical range of 2300 units would be diminished to 368·5, or, in other words, the faintest stars visible in that telescope would be distant only 368½ times the distance of stars of the first magnitude, instead of 2300 times that distance, if extinction of light did not exist. For Lord Rosse's telescope of six feet aperture the distance would be 422 units instead of the theoretical range of 3450.

The distance of star clusters and nebulæ, as computed by Sir W. Herschel, would, for the same reason, be considerably reduced. For example, the cluster 75 Messier, which he placed at a distance of 734 times the distance of stars of first magnitude, would, by the effect of extinction, be diminished to 228 times that distance.

Considering the distribution of the stars as nearly uniform and proportional to the space, and assuming as before an infinite extension of the Milky Way in the direction of its principal plane, Struve investigates the proportion which stars of different classes contribute to the apparent brightness of the Galaxy. He computes a table, from which he draws the following conclusions:—

"1. Admitting the extinction of light, the brightness of the Milky Way—supposed limitless in extent—is no longer necessarily infinite. Its brightness is now reduced to 3·3 times the brightness which would be produced by all stars

of 1 to 9 magnitude of Bessel which are situated in that direction, or the 12½ times that of the stars visible to the naked eye (in the same direction).

"2. The stars which lie beyond the range of Herschel's 20-feet telescope do not contribute more than twelve per cent. to the total brightness of the Milky Way.

"3. Subtracting the amount of light due to the lucid stars (1 to 6 magnitude of Argelander) we obtain 0·92007, which expresses the light of the background of the sky for the middle of the Milky Way."

Comparing the brightness of the Milky Way Zone with that of the celestial vault in the direction of the Galactic poles, he finds:—

"4. The total brightness of the sky in the direction of the Poles is only twenty-two per cent. of that in the middle of the Milky Way.

"5. The ratio between the brightness produced by stars of different classes in the two directions, viz., that of the Milky Way and that of its Poles, increases gradually as the stars become fainter.

"6. Subtracting the light of the lucid stars, we have the illumination in the direction of the Pole" (0·15170) "not even a sixth of the light of the Milky Way" (0·92007).

The number 25·672, found by Struve for the space-penetrating power of Herschel's gauging telescope, depends on the assumption that the Milky Way is of infinite extension in the direction of its principal plane. As I have shown, however, this assumption is not warranted by Sir W. Herschel's observations. The difference between the space-penetrating power of his telescope as estimated by Herschel and the result computed by Struve may be

equally well explained if we suppose the stars composing the Milky Way to "thin out" near the limiting range of Herschel's telescope. The optical power of his instrument *might* have enabled him to reach stars at a distance of 74·83 times that of a star of the sixth magnitude—if the stars were there; but if the stellar aggregation has sensibly diminished in density at this distance, the number of stars visible in his instrument would not be proportionately increased.[1]

That the Milky Way is *not* infinitely extended in the direction of its plane seems clearly shown by Sir John Herschel's observations in the Southern Hemisphere. Some of these have been already quoted in the chapter on "The Milky Way and Star Distribution."

In his *Outlines of Astronomy* (pp. 578, 579, 580, Tenth Edition) he says:—

"When examined with powerful telescopes, the constitution of this wonderful zone is found to be no less various than its aspect to the eye is irregular. In some regions the stars of which it is wholly composed are scattered with remarkable uniformity over immense tracts, while in others the irregularity of their distribution is quite as striking, exhibiting a rapid succession of closely clustering rich patches separated by comparatively poor intervals, and indeed in some instances by spaces absolutely dark *and completely void of any star*, even of the smallest telescopic magnitude [the italics are Herschel's]. . . . In some, for instance, extremely minute stars, though never altogether wanting, occur in numbers so moderate as to lead us irresistibly to the

[1] At a distance of 74·83 a sixth-magnitude star would be reduced in brightness about 9·37 magnitudes ("light ratio" = 2·512) or to magnitude 15·37. Herschel's original estimate of 61·18 would make his faintest stars 14·93 magnitude, which is perhaps nearer the truth. A distance of 25·672 would imply a magnitude of 13·04, which is about the *minimum visibile* of a 6-inch refractor—according to Pogson's formula. This is of course on the assumption of *no* extinction of light.

conclusion that in these regions we see *fairly through* the starry stratum, since it is impossible otherwise (supposing their light not intercepted) that the numbers of the smaller magnitudes should not go on continually increasing ad infinitum. In such cases, moreover, the ground of the heavens, as seen between the stars, is for the most part perfectly dark, which again would not be the case, if innumerable multitudes of stars too minute to be individually discernible existed beyond. In other regions we are presented with the phænomenon of an almost uniform degree of brightness of the individual stars, accompanied with a very even distribution of them over the ground of the heavens, both the larger and smaller magnitudes being strikingly deficient. In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars nearly of a size, and of no great thickness compared with the distance which separates them from us. Were it otherwise we should be driven to suppose the more distant stars uniformly the larger, so as to compensate by their greater intrinsic brightness for their greater distance, a supposition contrary to all probability. In others again, and that not unfrequently, we are presented with a double phænomenon of the same kind, viz., a tissue as it were of large stars spread over another of very small ones, the intermediate magnitudes being wanting. The conclusion here seems equally evident that in such cases we look through two sidereal sheets separated by a starless interval."

"Throughout by far the larger portion of the extent of the Milky Way in both hemispheres, the general blackness of the ground of the heavens on which the stars are projected, and the absence of that innumerable multitude and excessive crowding of the smallest visible magnitudes, and of glare produced by the aggregate light of multitudes too small to affect the eye singly, which the contrary supposition would appear to necessitate, must, we think, be considered unequivocal indications that its dimensions *in directions where these conditions obtain*, are not only not infinite, but that the space-penetrating power of our telescopes suffices fairly to pierce through and beyond it."

He then refers to Struve's speculations on the extinction of light, and says :—

"The objection alluded to, if applicable to any, is equally so to every part of the Galaxy. We are not at liberty to argue that at one part of its circumference, our view is limited by this sort of cosmical

veil which extinguishes the smaller magnitudes, cuts off the nebulous light of distant masses, and closes our view in impenetrable darkness; while at another we are compelled by the clearest evidence telescopes can afford to believe that star-strown vistas *lie open*, exhausting their powers and stretching out beyond their utmost reach, as is proved by that very phænomenon which the existence of such a veil would render impossible, viz., infinite increase of number and diminution of magnitude, terminating in complete irresolvable nebulosity. Such is, in effect, the spectacle afforded by a very large portion of the Milky Way in that interesting region near its point of bifurcation in Scorpio where, through the hollows and deep recesses of its complicated structure, we behold what has all the appearance of a wide and indefinitely prolonged area strewed over with discontinuous masses and clouds of stars which the telescope at length refuses to analyse. Whatever other conclusions we may draw, this must anyhow be regarded as the direction of the greatest linear extension of the ground plan of the Galaxy. And it would appear to follow, also, as a not less obvious consequence, that in those regions where that zone is clearly resolved into stars well separated and *seen projected on a black ground*, and where by consequence it is *certain* if the foregoing views be correct that we look out beyond them into space, the smallest visible stars appear as such, not by reason of excessive distance, but of a real inferiority of size and brightness." [The italics are Herschel's.]

From these remarks it seems perfectly clear that Struve's conclusions are quite irreconcilable with Sir John Herschel's observations.[1]

But apart from Struve's hypothesis of an infinite extension of the Milky Way in the line of sight, his assumption of stellar condensation in planes parallel to the principal Galactic plane—a sort of stellar atmosphere—seems highly improbable. A sidereal system forming a disc of limited thickness, but of infinite (or rather indeterminate) diameter,

[1] It should be stated, however, that Sir John Herschel's observations were not published till *after* the publication of Struve's memoir, and were therefore, of course, unknown to the great Russian astronomer.

although very improbable, is at least conceivable; but that this disc should increase in stellar density from its surface to its central plane, and then diminish in density again towards the opposite surface, seems too artificial an arrangement to represent a real law of nature.

With reference to the extinction of light supposed by Struve, Professor Grant says, in his *History of Physical Astronomy*: "If such an hypothesis were true, we might reasonally presume that, in consequence of the light being everywhere extinguished at the same distance, the Milky Way would present a uniform aspect throughout its course. As, however, observations of the actual aspect of the Milky Way do not accord with this conclusion, the hypothesis from which it is deduced is manifestly inadmissible."

In a memoir recently published on the apparent distribution of the stars visible to the naked eye,[1] Professor Schiaparelli discusses the question of the probable extinction of light in interstellar space. From a consideration of the numbers of stars of different magnitudes down to the fifth magnitude contained in the Harvard Photometry, he finds a value for the "constant of extinction" equal to 0·9190. With this co-efficient he computes a table of the extinction of light for stars down to the sixteenth magnitude—extending the Harvard scale by means of the light ratio 2·5119,[2] adopted by Pickering. From this it appears that the distance of stars of the fifth magnitude, which, on the assumption of *no* extinction, would be—with the assumed light ratio—6·31 times the distance of stars of the first

[1] *Sulla Distribuzione Apparente delle Stelle visibili ad Occhio Nudo, Pubblicazioni del Reale Osservatorio di Brera in Milano*, N. XXXIV., 1889.

[2] This is the light ratio now generally accepted by astronomers.

magnitude, is reduced by extinction to 5·269 times that distance. For stars of the sixth magnitude the distance is reduced from 10 to 7·576, and for stars of the sixteenth magnitude from 1000 to 65·548. He concludes therefore that for the naked-eye stars it is not of much importance whether we accept or reject the hypothesis of extinction. (His words are: "Per le stelle lucide adunque non è di molta importanza l'adottare l'ipotesi dell' estinzione piuttosto che il respingerla.") The extinction, however, for stars below the sixth magnitude would increase very rapidly, the light of tenth-magnitude stars being reduced from unity to the fraction 0·1324, and that of the sixteenth magnitude to the small fraction 0·0039, or more correctly to $\frac{1}{255}$ of its original amount. From these values it appears that *without* extinction stars at sixteenth-magnitude distance would shine as tenth magnitude.

Taking the number of stars down to the fifth magnitude contained in Argelander's *Durchmusterung* at 1024, and assuming that the stars contained in that catalogue include all those to tenth magnitude, of which the distance is reduced from 63·096 to 23·948, on the above scale, Schiaparelli finds that—considering the volumes of the sphere containing these stars—the number of tenth-magnitude stars visible in the whole heavens should be 120,180. But from the numbers in the *Durchmusterung* it appears that the actual number visible would be over 600,000 for the whole star sphere, or nearly five times the number required on the hypothesis of extinction. If then we accept the theory of extinction, he considers it necessary to assume that we are situated in a spherical cavity relatively free from stars, the stars increasing in number with increase of distance,

and for magnitudes below the tenth with very great rapidity. Hence it appears that the fundamental assumption of a uniform distribution of stars disappears from the brighter orders of stars, and to preserve it for the fainter orders the hypothesis of light extinction has been proposed. Schiaparelli concludes that such an hypothesis is not only unnecessary, but that it is ineffectual to produce the effect for which it was introduced,[1] and he considers that so rapid an extinction of light must be regarded as improbable.

He thinks, however, that there is nothing for or against the supposition of a very small and very slow extinction of light, for instance, the $\frac{1}{100}$th of the light at unit of distance proposed by Struve, or the $\frac{1}{800}$th suggested by Olbers. That celestial space is not everywhere equally transparent he thinks very possible, and he compares the vibrations producing light to those of sound, which are propagated through the air, but are annihilated when they reach the limits of the atmosphere.

Zöllner objected to the theory of extinction that the light absorbed would be converted into heat, but Schiaparelli replies that we cannot consider the ether as acting like a gas, or any other form of matter; and he points out that could we consider the ether as a gas, however rarified, the supposed extinction would produce an absorption in the

[1] His words are : "Cioè che noi ci troviamo in una specie di cavità sferica relativemente rara di stelle, dal cui centro esse si vadano addensando sempre più col crescere delle distanze, e per ordini superiori al decimo anche con una grandissima rapidità. Così scompare dagli ordini superiori la costante frequenza delle stelle, per conservare la quale negli ordini inferiori l' ipotesi dell' estinzione era stata invocata. Non solo dunque tale ipotesi non è necessaria al problema, come sopra si è detto, ma essa è impotente a raggiungere l' intento, per il quale era stata introdotta."

light of the stars when observed with the spectroscope, and the greater the distance of the star the greater would be the absorption. No such absorption has yet been observed.

Schiaparelli is disposed to believe that if any extinction of light really occurs, it is probably due to fine particles of matter scattered through interstellar space. He refers to the supposed constitution of comets' tails, of falling stars, and meteorites in support of this hypothesis. [Here we are reminded of Lockyer's "meteoritic plenum."]

He then investigates the question of the quantity of matter which would be necessary to produce the required extinction. He assumes with Gyldén the mean parallax of stars of the first magnitude as 0·″083, which corresponds to a distance of 369×10^{12} kilometres, and that for this distance the loss of light is $\frac{1}{800}$th, as supposed by Olbers. Taking the extinction as proportional to the distance (which we may do for short distances) we have the loss for each kilometre equal to unity divided by $259{,}200 \times 10^{12}$. Then supposing a cylindrical space extending from the observer to the star, of which the cross section is one square kilometre, it would be necessary that each cubic kilometre should contain as much matter as would suffice for the extinction of light on a transverse area expressed by one square kilometre, divided by $259{,}200 \times 10^{12}$, or one square millimetre divided by 259,200, which if collected would form an opaque spherical corpuscle of about a *microm* radius, or more exactly 1·μ038. Supposing this obscuring matter to be all divided into these small spheres, the quantity of such matter scattered through a volume equal to that of the terrestrial globe, if collected into one mass,

would form a ball only 10·65 millimetres radius (or about 0·42 inch).

In a sphere described with a diameter equal to the major axis of the earth's orbit, the collected matter would form a ball with a radius of 247 metres (or about 810 feet). For a sphere having a diameter equal to the mean distance of stars of the first magnitude, the collected corpuscles would form a globe of 307,000 kilometres radius, or nearly 48 times the mean radius of the earth. Schiaparelli considers that in these results there is nothing opposed to received ideas respecting the density of comets' tails, or the number of falling stars and meteorites supposed to exist in the Solar System.

If we suppose the mass of the obscuring corpuscles greater, say globes of one millimetre radius, it would be necessary to admit in the same space a quantity of matter a thousand times greater, and even this supposition would not lead to inadmissible results. But in this case the matter scattered through space would begin to surpass in volume that of the stars themselves.[1]

In conclusion Schiaparelli considers that there is nothing impossible in the idea of matter scattered through space in sufficient quantity to produce an appreciable extinction of stellar light, and especially in the case of very distant stars. In this way he thinks we may explain the apparent blackness of the sky on which the stars are spread,

[1] Schiaparelli's words are : " Cosi assumendo piccoli globi de 1 millimetro di raggio, bisognerebbe ammettere nel medesimo spazio una quantità di materia opaco di un volume totale mille volte più grande : e tale supposizione non condurebbe ancora a risultati inammisibili. In tale caso però la materia diffusa a questa modo per lo spazio comincierebbe a supera in volume quella raccolta mi corps lucenti, che chiamiamo stelle."

without having recourse to the hypothesis of a limited number of stars, or to any conjectures as to the constitution of the luminiferous ether. A similar suggestion has been advanced by Mr. Monck to explain the limited number of the visible stars.

I have already stated in the present chapter the evidence which seems opposed to the hypothesis of any extinction of light whatever in interstellar space, at least as far as our largest telescopes can reach. *Beyond* that distance, however, the extinction of light may perhaps become appreciable, and may very possibly account for the fact that the number of the *visible* stars is finite.

CHAPTER XVII.

PROCTOR'S VIEWS.

IN his very interesting work *The Universe and the Coming Transits* (1874), the late Mr. Proctor gave a summary of the views advanced by Kepler, Huygens, Wright, Kant, Lambert, and Michell. These have been already discussed in Chapter XIII. With reference to these theories Proctor says: "I do not hesitate to say that Wright, Kant, Lambert, and Michell did more to advance men's ideas respecting the constitution of the sidereal universe than all the astronomers who lived before the time of Sir W. Herschel" (p. 176). As the long quotation I have given from Wright's rare work will show, he was undoubtedly the originator of the "disc" theory of the Milky Way.

This hypothesis, popularly attributed to Sir W. Herschel, was abandoned by that great astronomer himself in his later writings, as Struve has clearly demonstrated, and as Proctor has ably maintained in recent years. Struve's researches on the subject have been discussed in the preceding chapter. In the present chapter I propose to give some account of Proctor's objections to the "disc" theory, and of his own views on the construction of the sidereal heavens.

Proctor thinks that Sir W. Herschel's elaborate series of papers (which are scattered through 37 volumes of the *Philosophical Transactions* of the Royal Society, 1780 to 1818) are worthy of more careful study than they usually receive, a study which will clearly show that the "disc" theory of the Milky Way, definitely propounded by Herschel in 1785, was distinctly abandoned by him in 1811. The account given by Arago of Sir W. Herschel's theories has unfortunately been accepted by many English writers on astronomy; but according to both Struve and Proctor this account is quite untrustworthy, and entirely misinterprets Herschel's views on the subject.

The popular idea that Herschel considered *all* nebulæ as external galaxies is quite erroneous. Even in 1785 he looked on the nebulæ as probably belonging to two distinct groups; some possibly forming portions of the Milky Way, while others he considered as probably external galaxies. At this period he seems to have held the opinion that all nebulæ had a stellar constitution. The spectroscope had not then been invented, and he attributed his failure to resolve some of these objects into stars to deficiency of optical power in his telescope. His opinion was in 1789 still unchanged, when he compared the different forms of nebulæ to plants in the successive stages of their growth and subsequent decay.

In the paper of 1802 he clearly shows his changed views on the construction of the Milky Way. He says: "The milky appearances deserve the name of clustering collections, as they are certainly much brighter about the middle, and fainter near their undefined borders. . . . We may indeed partly ascribe the increase both of brightness and

compression to a greater depth of the space which contains the stars; but this will equally tend to show their clustering condition; for, since the increase of brightness is gradual, the space containing the clusters in stars must tend to a spherical form if the gradual increase of brightness is to be explained by the situation of the stars."

The recognition of this *clustering* tendency in the faint stars producing the Milky Way light is of course in direct opposition to the "disc" theory, which rests on the fundamental assumption of a generally *uniform* stellar distribution.

Again in the paper of 1814 he says: "This tendency of clustering seems chiefly to be visible in places extremely rich in stars. In order, therefore, to investigate the existence of a clustering power, we may expect its effects to be most visible in and near the Milky Way"; and with reference to the irregular clustering portions: "Those which are in and very near the Milky Way may be looked upon as so many portions of the great mass drawn together by the action of a clustering power, of which they tend to prove the existence."

These remarks show clearly enough the altered aspect of Herschel's views, and we may well ask with Struve, "pourquoi les astronomes ont-ils maintenu généralement l'ancien système sur la voie lactée, énoncé en 1785, quoiqu'il eût été entièrement abandonné par l'auteur lui-même."[1] It seems high time therefore that this "disc" theory should be omitted from our text-books of astronomy, as it most certainly does not represent the more mature views of the great English astronomer.

[1] *Études d'Astronomie Stellaire*, p. 49.

It appears from Herschel's subsequent papers—published in 1817 and 1818—that he did not formulate any very definite theory to replace the one he had abandoned. Proctor, however, maintains that the principle enunciated in these papers—viz., "that the telescopic powers necessary to reveal and to resolve star groups, or particular star orders within groups, afford an indication of the distance at which these groups or orders lie"[1]—is unsound. In support of this opinion Proctor refers to observations of Sir W. Herschel of limited regions of the heavens in which he found the brighter stars easily visible with low powers, while the faintest were individually invisible with his largest telescopes. On Herschel's principle this would imply that these star groups were of a cylindrical or conical shape, with their axes pointing directly towards the earth —an utterly improbable arrangement, and forming an hypothesis which, Proctor justly says, is "altogether untenable."

By the application of this new but clearly erroneous principle, Herschel obtained results on which Struve subsequently founded his hypothesis of an infinite extension of the Milky Way in the direction of its principal plane. Herschel said that "when he could not resolve the Milky Way it was because it is unfathomable." This Struve translates: "Si nos jauges cessent de résoudre la voie lactée en étoiles, ce n'est point parce que la nature en est douteuse, mais parce qu'elle est insondable (fathomless)."[2] According to Proctor the use of the French word "si" for the English "when" changes the whole meaning of the

[1] These are Proctor's words, not Herschel's.

[2] *Études d'Astronomie Stellaire*, p. 34.

sentence. However this may be, it seems evident that Herschel's principle of the irresolvability of star clusters, being a test of distance, would have led to the conclusion upon which Struve based his hypothesis of the extinction of light.

Proctor says : " Where Herschel *thought he was penetrating to the extreme limits of the sidereal system, he was in reality only analysing more and more searchingly an aggregation in which many orders of stars were mixed up. What he failed to do was not (as he supposed) to sound the Galaxy, but to recognise as separate stars the minutest orders of orbs included within such aggregations.*"[1] All observations of star clusters and stellar aggregations seem to show the correctness of this conclusion.

Proctor then proceeds to examine the evidence afforded by Sir John Herschel's observations in the Southern Hemisphere. He justly remarks that the " Coal Sack " near the Southern Cross, and indeed the general aspect of the Galaxy in this region, indicates " that the Milky Way, in this neighbourhood at any rate, is really what it appears to be, a belt or zone of stars separated from us by an apparently starless interval." With this opinion I fully concur. It certainly seems utterly improbable that the nearly circular blank space, known as " the Coal Sack," should represent a tunnel through a disc, of which the thickness is comparatively small, while its diameter, on Struve's hypothesis, stretches out almost to infinity. A straight tunnel-shaped opening of infinite length, or nearly so, with its axis pointing directly towards the earth, would form an extraordinary phenomenon, even in a solitary instance ; yet there

[1] *The Universe and the Coming Transits*, p. 217. The italics are Proctor's.

are several[1] somewhat similar cases to be found in the Milky Way. That *all* these should represent tunnels radiating from a common centre is quite beyond the bounds of probability, and indeed such an hypothesis seems unworthy of serious consideration.

Sir John Herschel seemed inclined to consider the Galaxy as probably forming "a flat ring," although it does not appear that he *definitely* adopted this theory. His conclusion that we cannot "without obvious improbability refuse to admit that the long lateral offsets which at so many places quit the main stream and run out to great distances, are either planes seen edgeways, or the convexities of curved surfaces viewed tangentially rather than cylindrical or columnar excrescences bristling up obliquely from the general level,"[2] is objected to by Proctor, who thinks that "the obvious improbability seems to lie altogether the other way."

A glance at Dr. Boeddicker's drawing of the Milky Way will, I think, convince most people that Proctor's view is the correct one, and indeed it seems evident that the probability of a *number* of planes or curved surfaces being so placed as to be seen edgeways is quite as small as the chance of a number of tunnel-shaped openings in a comparatively thin disc being all directed to the centre of the disc.

Sir John Herschel considered that "the tendency to aggregation of the brighter stars on the Milky Way is quite imperceptible among stars of a higher magnitude than the eighth, and except on the very verge of the Milky

[1] And *many* small telescopic ones.

[2] *Outlines of Astronomy*, Tenth Edition, p. 574.

Way itself, stars of the eighth magnitude can hardly be said to participate in the general law of increase."

"For the ninth and tenth the increase, though unequivocably indicated over a zone extending at least 30° on either side of the Milky Way, is by no means striking. It is with the eleventh magnitude that it first becomes conspicuous, though still of small amount when compared with that which prevails among the mass of stars of magnitudes inferior to the eleventh, which constitute sixteen-seventeenths of the totality of stars within 30° of either side of the Galactic circle."[1]

From this he concludes "that the larger stars are really nearer to us (taken *en masse*, and without denying individual exceptions) than the smaller ones. Were this not the case, were there really among the infinite multitude of stars, constituting the remoter portions of the Galaxy, numerous individuals of extravagant size and brightness, as compared with the generality of those around them, so as to overcome the effect of distance and appear to us as large stars, the probability of their occurrence in any given region would increase with the total apparent density in that region, and would result in a preponderance of considerable stars in the Milky Way, beyond what the heavens really present, over its whole circumference."[2]

In opposition to the view expressed in the opening sentence of the above quotation, Sir John Herschel says in his *Outlines of Astronomy* (p. 568, Tenth Edition): "If we take in the whole amount visible to the naked eye, we shall perceive a great increase of number as we approach the borders of the Milky Way." The discrepancy between

[1] *Cape Observations*, p. 383. [2] *Ibid.*, p. 383.

these two statements Herschel explained, in a letter to Proctor, by saying that the passage in the *Outlines* refers "rather to a vague naked-eye impression than to the statistical result of actual enumeration."[1] From an examination of the stars down to only the sixth magnitude Proctor found a well-marked tendency to crowding on the Milky Way. But in this investigation he omitted the "coal sacks" and vacuities, which Heis and Gould show to be filled in with faint nebulous light, and the delineation of the Galaxy used in his inquiry was not very accurate. He found that "the whole of the Galaxy covers between one-tenth and one-eleventh of the heavens"; but the drawings of Boeddicker, Gould, and Heis show a considerably greater extension. Houzeau's drawing of the Milky Way, however, covers, according to Plassmann, about one-tenth of the star sphere. But his drawing is very deficient in detail.

In the chapter on the Milky Way I have shown that for the naked-eye stars north of the Equator, shown by Heis, the number of stars on the Milky Way is slightly in excess of that due to its area. This remark also applies to Houzeau's drawing of the Milky Way in both hemispheres.[2] A similar result was found by Major Markwick for Dr. Gould's stars to the seventh magnitude, south of the Equator (*The Scenery of the Heavens*, p. 265). Possibly a careful investigation of Dr. Boeddicker's drawing might show a still more marked tendency to aggregation of the lucid stars on the Milky Way; but the computation would be a matter of no small difficulty, owing to the complicated ramifications of the Galaxy as delineated

[1] *The Universe and the Coming Transits*, p. 194.
[2] *The Observatory*, April 1890.

by Boeddicker. From an examination of the stars in Behrmann's Atlas I have, however, been able to verify Proctor's "rich southern region" extending from Canis Major to the Southern Cross.

All the stars contained in Argelander's *Durchmusterung* (9½ or 10th magnitude, equal to Herschel's 11th) were plotted by Proctor on a single chart (equal surface projection). In this remarkable chart the course of the Milky Way is clearly defined by a well-marked increase of stellar density. Proctor says: "In the very regions where the Herschelian gauges showed the minutest telescopic stars to be most crowded, my chart of 324,198 stars shows the stars of the higher orders (down to the eleventh magnitude) to be so crowded that by their mere aggregation within the mass they show the Milky Way with all their streams and clusterings. . . . It is utterly impossible that excessively remote stars could seem to be clustered exactly where relatively near stars were richly spread. This might happen, no doubt, in a single instance; but that it could be repeated over and over again, so as to account for all the complicated features seen in my chart of 324,198 stars, I maintain to be utterly incredible."[1]

This argument seems quite unanswerable, and should, I think, serve to completely upset the original "disc" theory of the Milky Way, which, like many other errors, has persistently held its ground in astronomical text-books. The results derived from Proctor's chart are, however, in good agreement with the views expressed by Sir W. Herschel in his *later* writings, and it certainly does seem strange that the opinions held by Herschel, when, as Proctor says, "his

[1] *The Universe and the Coming Transits*, p. 200.

labours were but beginning, should be adopted by future astronomers in preference to those which were the fruits of his ripened experience."[1]

Proctor also points out that if we consider the Milky Way as consisting of stars comparable in size and brilliancy with the brighter stars which stud our midnight sky, we must conclude that it lies at a vastly greater distance from our system than the lucid stars, and for this reason we should not expect to find any coincidence between the course of the Galactic streams and the configuration of the brighter stars which are optically projected on the Milky Way. Several remarkable coincidences of the kind are, however, noted by Proctor, for instance, in Cygnus and in Scorpio; and numerous examples of the apparent connection of star streams with rays and streams of Milky Way light may be traced in Dr. Boeddicker's drawing (see Plate IV.), which was executed from naked-eye observations only. Examined with a binocular I find that a similar relation exists in many places between the convolutions of the Galaxy and the small stars below the limit of naked-eye vision.

I quote the following from my observing book: "1889 Oct. 26, North of α Cygni, and near ξ and ν Cygni, the nebulous light of the Milky Way, as seen with binocular, seems to cling round and follow streams of small stars in a very remarkable way; numerous small "coal sacks" and rifts are visible, in which comparatively few stars are to be seen with the binocular." This observation has been fully confirmed by photographs of this region obtained by Dr. Max Wolf in 1891.

In some cases noted by Sir J. Herschel at the Cape of

[1] *The Universe and the Coming Transits*, p. 106.

Good Hope he found a sharply defined offshoot from the Milky Way with a tolerably bright star situated at the extremity of the projection.

It seems impossible to escape from the conviction that a physical connection exists between these nebulous rays and the star streams with which they apparently coincide. That so many coincidences should be due to mere accident seems wholly improbable, and obviously leads to the conclusion that the faint stars forming the nebulous light are, in reality, mixed up with the brighter stars, and do not lie at an immense distance behind them.

Proctor also calls attention to the apparent coincidence of streams in the irregular nebulæ with streams of small stars visible in the same telescopic field of view. The evident connection between the nebulous light of the great Orion nebula and the stars visible in its vicinity—as shown by the spectroscope—clearly implies that stars and nebulous matter may co-exist in the same regions of space.

The great majority of star clusters are found along the course of the Milky Way, while the irresolvable nebulæ seem to aggregate towards the poles of that zone.

The strongest evidence, however, in favour of the association between stars, star clusters, and nebulæ Proctor finds in the "Magellanic Clouds" in the Southern Hemisphere. In the larger of these "clouds" in particular we see stars of the seventh, eighth, ninth, and tenth magnitudes apparently mixed up with fainter stars and "clusters of all degrees of resolvability," in a space which, judging from its probably globular form, must be of small dimensions in comparison with its distance from the Solar System.

It seems possible to imagine that *one* such object might

be the result of foreshortening in a figure of cylindrical or conical shape, with its axis pointing towards the earth; but, as Sir John Herschel remarks, "such an adjustment, improbable enough in one case, must be rejected as too much for fair argument in two. It must, therefore, be taken as a demonstrated fact, that stars of the seventh or eighth magnitude and irresolvable nebulæ may co-exist within limits of distance not differing in proportion more than as 9 to 10."[1] This argument may, I think, be extended to the Pleiades, where, in a space of apparently spheroidal form, photography shows us stars of all magnitudes, from the third to the seventeenth magnitudes, mixed up with irresolvable nebulosity, which seems to cling round the brighter components. Dr. Boeddicker's drawing shows that this remarkable cluster is connected with the main stream of the Galaxy by a faint nebulous branch.

Proctor was of opinion that the two Magellanic Clouds may possibly form external galaxies. He says (*Knowledge*, March 1886): "We have in the Magellanic Clouds every one of the features which our Galaxy would present if seen from a distance. There are stars of the seventh magnitude which we may regard as being suns like Sirius, Vega, Altair, and other stars of the giant order, removed to many times the distance of the leading orbs of our Galaxy. Then there are fainter stars of all orders down to those so faint that they cannot be separately discerned with the most powerful telescopes we have, and appear only as milky nebulosity. There are star clouds of all orders; and, lastly, there are vast regions of gaseous matter akin to the great Fish-mouth nebula in Orion, and the great

[1] *Outlines of Astronomy*, Tenth Edition, p. 657.

key-hole nebula in the constellation Argo. If the *nubeculæ* are not external galaxies resembling our own, they present at any rate all the appearances which such galaxies would present from a very distant standpoint."

With reference to the question of the resolvability of the star groups as a test of distance, Proctor points out that if a star group—the components of which are equal in magnitude, and individually visible to the naked eye—be supposed to pass away rapidly into space, each separate star would become fainter and fainter, and the distances separating them smaller and smaller, as the group receded from the eye. Now, if the "distances between them became too small to be distinguished while the stars themselves remained visible, clearly there would result a nebulosity of appearance."

"But suppose that, on the contrary, the stars of the group became invisible when the group was at such a distance that the intervals separating star from star would not be indistinguishable (if only the stars were brighter). Then clearly the group would vanish with increasing distance without ever becoming nebulous. Clearly also, if a telescope were employed to bring the retreating group into view, the same conclusions would hold good. A group which would become nebulous to the naked eye before vanishing would become so when examined under a telescope, let the telescope's power be what it might; while a group which would vanish without becoming nebulous to the naked eye would not become nebulous before vanishing under telescopic vision, whatever the telescopic power employed."[1] From this reasoning—which seems to be

[1] *Essays on Astronomy*, pp. 340, 341.

sound—it is obvious that the resolvability of a star group, in which the components are of equal brightness and equally distributed, depends more on the constitution of the cluster than on its distance from the earth.

A similar consideration is applicable to clusters containing stars of different classes of brightness. "Supposing a group of this kind to be passing away into space—as in the former case—the question whether it would become nebulous at any stage or stages of its progress would depend on the question whether or not the orders of stars about to disappear individually were congregated so closely that the eye could not distinguish the distances separating them."[1]

Proctor considers that the correctness of the above reasoning is shown by Sir John Herschel's observations of the Magellanic Clouds. In the case of the smaller "cloud" (or *nubecula minor*) Herschel found the middle of the cloud clearly resolved into stars, while its edges remained irresolvable with his 18¼-inch reflector. He says: "The edge of the smaller *cloud* comes on as a mere nebula. . . . We are now *in the cloud.* The field begins to be full of a faint light, perfectly irresolvable. . . . I should consider about this place to be the body of the *cloud* which is *here* fairly resolved into excessively minute stars, which, however, are certainly seen with the left eye. . . . The borders fade away quite insensibly, and are less or not at all resolved. . . . This seems to be the body of the *cloud.* It is a fine rich large cluster of very small stars 12 . . . 18 magnitude which fills more than many fields, and is broken into many

[1] In the above considerations the question of the supposed extinction of light by the ether is of course set aside.

knots, groups and straggling branches, but *the whole* (that is, the whole of the clustering part) is clearly resolved. . . . The lower part of the sweep (*i.e.*, at 162° N.P.D.) contains a good deal of loose light, and is evidently the border of the Nubecula Minor; but there are not many stars, and the light is perfectly irresolvable and not congregated into knots or distinct nebulæ."[1]

Now it is evident that, had the Nubecula Minor a great linear extension into space, the central portions would be more difficult to resolve into stars than the borders of the cloud. The above observations show that the exact opposite is the case, and obviously negatives the assumption of any great extension of the cluster in the line of sight. It would therefore seem to be clearly proved that the irresolvability of a star cluster is no proof of enormous distance, and that the stars visible to the naked eye in the Milky Way and elsewhere are not *necessarily* at a greater distance from us than the small stars composing the Galaxy.

Proctor finds that the nebulæ, when charted, seem to run into streams or branches apparently connected with streams of stars, and he considers that this fact indicates a real and not merely an accidental association, leading us to the conclusion that the stars and nebulæ form portions of one and the same sidereal system.

Charting the stellar "proper motions" Proctor discovered that in many parts of the heavens the stars are apparently travelling together in systems. For instance, he found that the five stars of "The Plough," β, γ, δ, ϵ, and ζ Ursæ Majoris, are all moving in nearly the same direction through

[1] *Cape Observations*, pp. 145, 146.

space[1]—at least, apparently—and he predicted that if the motion in the line of sight could be determined by the spectroscope, all would be found to be moving either towards or away from the earth. This prediction was verified two years later by Dr. Huggins, who found that not only were the spectra of all five stars similar in character, but that *all* were receding from our system at the rate of about 20 miles a second. Other examples of apparently drifting star systems are found in Gemini and Taurus, especially in the Pleiades. The systematic star drift here referred to is of course distinct from that due to the Sun's motion in space. This is obvious in the case of the five stars in "The Plough," where the motion is nearly *towards* the "apex" of the solar motion instead of away from it.

Proctor calls attention to the numerous instances of "star streams" and "star sprays" which may be traced in various parts of the heavens, both among the stars visible to the naked eye and also among the fainter stars shown in the charts of Argelander and Chacornac. It seems improbable that *all* these stellar reticulations should be due to accidental arrangement, and the apparent coincidence of many of them with streams and rays of Milky Way light adds weight, I think, to the hypothesis that they have a real and not merely an imaginary existence. Examples of this "stream"-forming tendency have been referred to in Chapter X.

[1] Two small stars, Alcor and another, near ζ also participate in this motion. Dr. Auwers' subsequent determinations have, however, shown that in three of Proctor's stars, β, γ, and δ, the "proper motion" is small and doubtful.

Considering Sir W. Herschel's later views of the construction of the Galaxy, and Sir John Herschel's suggestion that its form might be that of a flat ring seen edgeways, Proctor was led to propose a new theory of the Milky Way, which represents it as forming a sort of spiral stream in space. The well-known "gap in Argo" he imagines as due to an opening between two of the spiral branches, and thinks that this gap could not possibly be explained either on the "cloven disc" or "flat ring" theory.

Dr. Gould, however, in the charts of the *Uranometria Argentina*, shows this gap as filled in with faint nebulous light. The "Coal Sack" near the Southern Cross Proctor explains by a loop in the spiral, and the great brilliancy of the Galaxy in this region by the comparative proximity of one of the spiral branches to our system. But, on this hypothesis, one side of the vacuity should be somewhat brighter than the other, one portion of the spiral branch being nearer to the eye. Sir John Herschel's drawing of the Milky Way, made at the Cape of Good Hope, shows a general uniformity of brightness in the nebulous light surrounding the "Coal Sack," and in Dr. Gould's delineation no well-marked inequality of brightness is perceptible in the bounding nebulosity. Proctor, however, points out that the difference of brilliancy would be slight.

The whole aspect of the Milky Way in this vicinity suggests, I think, that the "Coal Sack" is a real, and not merely an apparent, opening through the Galactic Zone. Proctor applies to these circular openings reasoning similar to that applied by Sir John Herschel to the Magellanic Clouds, and concludes that, "*if they are really openings at all*, they are openings through a system which is not very

much deeper—measured in the direction of the line of sight —than the greatest width of the aperture itself."[1] With this opinion I fully concur, but not with the theory that the "Coal Sack" is formed by a loop in a stellar stream. Sir John Herschel's gauges at the Cape of Good Hope show that the "Coal Sack"—although apparently blank to the naked eye—is by no means devoid of telescopic stars. This is confirmed by Dr. Gould, who (in the charts of the *Uranometria Argentina*) shows this remarkable vacuity as filled in with faint nebulosity.[2] We cannot therefore consider it as a *perfect* opening; but this does not detract from the argument in favour of its being a perforation through a comparatively thin stratum of stars.

Proctor attributes the fading away of the "broken branch" in Ophiuchus (near 70 Ophiuchi) to increase of distance in the spiral stream in that direction; but the appearance of this branch, as drawn by Boeddicker and Heis, tends, I think, to negative this hypothesis. In Heis' drawing the branch is shown rather *brighter at its extremity* (near 70 Ophiuchi) than at the point where it leaves the main Galactic stream. Boeddicker's representation of the Milky Way in this region is in fairly close agreement with Heis' delineation, but agrees rather better with its general appearance, as I see it. The description of the Milky Way as drawn by Dr. Gould (see Chapter IX.) shows, I think, that the supposed division of the Galaxy into two streams, from Aquila to the Southern Cross, is more apparent than real, and that the intricate convolutions of the Milky Way

[1] *The Universe and the Coming Transits*, p. 332. The italics are Proctor's.

[2] Photographs recently taken in the Southern Hemisphere also confirm this.

in this vicinity cannot well be represented by the hypothesis of a simple bifurcation.

Proctor sums up his general conclusions in the following words: "The sidereal system is altogether more complicated, altogether more varied in structure, than has hitherto been supposed. Within one and the same region co-exist stars of many orders of real magnitude, the greatest being thousands of times larger than the least. All the nebulæ hitherto discovered, whether gaseous or stellar, irregular, planetary, ring formed, or elliptic, exist within the limits of the sidereal system. They all form part and parcel of that wonderful system whose nearer and brighter parts constitute the glories of our nocturnal heavens."

CHAPTER XVIII.

INFINITE SPACE AND A LIMITED UNIVERSE.

One Wonderful, enough for Man to know!
One Infinite, enough for Man to range!
One Firmament, enough for Man to read!

YOUNG.

IT is impossible for our minds to imagine space as limited by any conceivable boundary. With every mental effort to impose upon it any imaginable limits we feel ourselves irresistibly impelled to "break through the barriers of the heavens," and carry our thoughts beyond the boundary which we have vainly attempted to assign. We are therefore compelled to consider that space is infinite and boundless. On the other hand, any attempt to grasp mentally this endless extension, this ever-widening infinitude, we find to be equally futile, and we are finally forced to confess that both limited and infinite space are alike unthinkable by the utmost efforts of the human intellect.

What then is the construction of the visible universe? the starry heavens as we see them? Some unreasoning people suppose that the number of the visible stars is infinite, or nearly so, but this is quite a mistake. The number visible in our largest telescopes, although of course

considerable, is only *comparatively* large, and compared with an infinite number must be considered as merely a drop in the ocean. The number visible to the naked eye, even with very good eyesight, is not only comparatively but *absolutely* small, not much exceeding 7000 for the whole heavens; and perhaps double this number would exhaust those which can be seen by persons gifted with *exceptionally* keen vision. Those who do not possess the power of effective enumeration estimate the number visible to the naked eye as considerably greater than is really the case. This is partly due to the irregular distribution of the lucid stars over the celestial vault, and partly to the effect which the aspect of the starry sky produces on the imagination; the fact of the stars increasing in number as they diminish in brightness inducing us to suspect the presence of points of light which we do not actually see. An attempt to count those seen with certainty in any selected portion of the sky will, however, convince any intelligent person that the number visible to ordinary eyesight, instead of being large, is really very small, and that the idea of a countless multitude is simply a popular fallacy based on an optical illusion.

As I have elsewhere shown,[1] it may be proved mathematically that, supposing the number of stars infinite and equally distributed through infinite space, if there is no extinction of light in the ether, the whole heavens should shine with the brightness of the Sun. Such is clearly not the case. On the clearest nights the amount of light afforded by the stars is, on the contrary, very small, and the comparative blackness of the background on which they

[1] *The Scenery of the Heavens*, p. 274.

are scattered is sufficiently obvious.[1] The number of the *visible* stars cannot therefore be infinite. If we assume with Struve that the light of very distant stars suffers total extinction in the ether of space—an assumption, however, which I have elsewhere shown to be improbable—it follows that at a certain distance the light of all the stars beyond must be cut off, and that the most powerful telescopes which can ever be constructed by man will fail to pierce through the "cosmical veil" which shrouds the most distant stars from our view. It follows, therefore, that whether an extinction of light does or does not take place, the number of the *visible* stars must necessarily be limited.

An indication of this approaching limitation to telescopic vision is afforded by the fact that M. Celoria, using a small telescope, of power barely sufficient to show stars to the eleventh magnitude, found that he could see almost exactly the same number of stars near the Northern Pole of the Milky Way as were visible in Sir William Herschel's large reflector! indicating that—here at least—no increase of optical power will materially augment the number of stars visible in that direction. In fact, the smaller telescope seems here sufficient to pierce through the stellar stratum into the void beyond; a result which affords further evidence against the hypothesis of an extinction of light in the ether. For Herschel's gauging telescope certainly revealed far fainter stars than those of the eleventh magnitude in other portions of the heavens. It should therefore

[1] According to Miss Clerke (*System of the Stars*, p. 7) the total light of all stars to 9½ magnitude is about $\frac{1}{800}$th of full moonlight. M. G. l'Hermite found for the total amount of starlight $\frac{1}{10}$th of moonlight, but this estimate is evidently much too high.

have shown fainter stars at the Galactic Pole also, if such stars existed in that region of space. Their absence seems certain proof that very faint stars do *not* exist in that direction, and that here, at least, our sidereal universe is limited in extent.

An examination by Miss Clerke of Professor Pickering's catalogue of stars surrounding the North Pole shows that "the small stars are overwhelmingly too few for the space they must occupy if of average brightness; and they are too few in a constantly increasing ratio."[1] Here again a "thinning out" of the stellar stratum seems clearly indicated, and suggests that a limit will ere long be reached, beyond which our most powerful telescopes will fail to reveal any further stars. (See Appendix, Note Q.)

In my *Planetary and Stellar Studies* (p. 234) I have estimated the probable number of the visible stars at 70 millions. To show that this estimate is not largely in error I may mention that Professor Newcomb estimates the number of stars at 100 millions, and Professor Young also gives 100 millions as the probable number visible in the great Lick telescope. M. Faye, in his *L'Origine du Monde*,[2] computes the number visible to the sixteenth magnitude at 31 millions.

Admiral Smyth says (*Celestial Cycle*, vol. i., p. 270): "We may now safely declare that nearly one hundred millions of suns are within telescopic reach"; and in a note he mentions that M. Chambre in 1653, arguing with the astrologers of that day, ridiculed them for limiting the number of stars to 1028 (about the number recorded in the ancient catalogues), and "declared that the eight

[1] *Nature*, August 9th, 1888. [2] Second Edition, p. 180.

spheres, properly packed, would stow away no fewer than 71,209,600." The reference to "the eight spheres" is of course absurd, but I merely quote Chambre's opinion to show that even *his* theory of the universe—such as it was—did not require an *infinite* number of stars.

It will be seen, therefore, that the total number of stars visible, even in our largest telescopes, is comparatively small. Indeed, compared with an *infinite* number it may be almost considered as a vanishing quantity. In a ten-acre field of ripe oats the number of grains of corn [1] probably exceeds the number of the visible stars; and we should have to multiply the number of the stellar hosts by at least 10 to obtain the number of human beings now living on our comparatively tiny world!

The question naturally suggests itself, How is this limited number of stars to be explained? If space be really infinite—as we seem bound to suppose—it would be reasonable to expect that the number of stars would be practically infinite also. But, as I have just shown, the number of the *visible* stars is certainly finite, and unless we admit an extinction of light in interstellar space the *total* number of stars in the universe must be finite also.

The diagram representing the so-called "disc theory" of Sir William Herschel, which figures in so many astronomical text-books, clearly shows that its illustrious author considered that the vast cluster which forms—on this theory—our visible universe is limited in dimensions: in fact, "an islet in the boundless void."

[1] There are 43,560 square feet in an acre. Taking 10 ears of corn to the square foot, and 30 grains in each ear—probably a moderate estimate—we have the number of grains on 10 acres equal to 130,680,000.

Struve's modification of the "disc theory," namely, a disc of a certain thickness, but of infinite—or at least indeterminate—diameter, seems a very improbable hypothesis. Even on this theory our sidereal system is supposed to be limited in the direction of its thickness.

If Struve's theory were to be accepted, we should also be obliged to accept his hypothesis of the extinction of light; for otherwise the Milky Way should be much brighter than it is. With an infinite extension the Galaxy would of course shine with the brightness of the Sun. The comparatively feeble gleam of the Milky Way on even the clearest nights should, I think, be sufficient to convince the thoughtful observer that its light is *not* due to a vastly extended stratum of stars. Even Sir John Herschel's reflecting telescope of 18¼ inches aperture (now far surpassed in space-penetrating powers by our modern instruments) sufficed in some places in the southern heavens to show the component stars of the Milky Way on a *black* background devoid of any nebulous light. With reference to one of his Galactic sweeps he says, "The northern end of the zone, though pretty rich in *stars*, is yet quite free from brightness of ground. It is as black as a coal," clearly showing that his optical power could—here at least—penetrate fairly through the stellar stratum into the starless void beyond.

Photographs of portions of the Milky Way in the Northern Hemisphere, taken at the Paris Observatory, show the fainter stars as points of light, on a perfectly black ground devoid of all nebulosity. More powerful telescopes will probably disclose the existence of many fainter stars, but all the evidence we have at present points to the con-

clusion that the utmost limit of telescopic vision will very soon be reached, and that the most powerful telescopes which man can construct will ultimately show that the stars, even in the richest portions of the Galactic Zone, are strictly limited in number.

The general aspect of the Milky Way seems, I think, sufficient to negative the "disc theory." The numerous convolutions, streamers, rifts, and "coal sacks" depicted in the drawings of Boeddicker and Gould can hardly be explained by the honey-combed structure of a stellar disc, and one finds it difficult to resist the conclusion that the apparent streams of nebulous light, which are seen branching out in all directions from the Galactic Zone, are really streams of stars in space, and that the apparent openings known as "coal sacks" are in reality perforations through a stellar stratum of comparative thinness, and not cosmical tunnels of immense length pointing directly towards the earth.

But even if we knew the exact constitution of the great sidereal cluster of which our Sun forms a member, this would not help us to answer the question, How is it that, if space is infinite, the number of visible stars is finite? A consideration of our own Solar System and its spatial surroundings may, however, assist us in framing some probable hypothesis. We know that the dimensions of Jupiter's system of satellites are small in comparison with the dimensions of the Solar System, and that the diameter of the Solar System, measured across the orbit of the outermost planet Neptune, is small compared with the distance which separates us from the nearest fixed star. Roughly speaking the distance of *a* Centauri is 9000 times the distance

of Neptune from the Sun. Hence if we represent the orbit of Neptune by a circle one foot in diameter, the void space surrounding the Solar System will be represented by a circle of 9000 feet, or nearly $1\frac{3}{4}$ miles across.

Here we have a vast sphere, about 50 billions of miles in diameter, quite devoid of matter as far as we know, and containing nothing except perhaps a few comets and meteoric swarms.

Now, we may infer from analogy that the stars are probably suns forming the centres of planetary systems similar to our own. The immense distance of the stars from the earth would of course render such planets as ours invisible even in our largest telescopes. Even if the "giant planet" Jupiter were revolving round *a* Centauri at the same distance from that star that it is from our Sun, it would be utterly invisible to us even in the great Lick telescope.

In certain rare cases, however, we seem to see planets of a much larger size revolving round some of the stars. I refer of course to those binary or revolving double stars in which a bright star is accompanied by a companion very much fainter than itself. Among these may be mentioned Sirius, δ Cygni, 85 Pegasi, and 99 Herculis. The companion of Sirius is about 11 magnitudes fainter than its brilliant primary. This implies that Sirius is about 25,000 times brighter than its small attendant. If both are of the same intrinsic brightness, the ratio of their diameters would be 158 to 1, and the mass of Sirius nearly 4 million times the mass of the companion.

Now the latest determination of the distance of Sirius, combined with my elements of the orbit, makes the mass of Sirius about three times the mass of the Sun.

As the evidence of the spectroscope indicates that Sirius is a hotter star than our Sun, and therefore presumably brighter, surface for surface, we may not perhaps be very far wrong in assuming its diameter at 2,000,000 miles. This would make the diameter of the companion about 12,600 miles, or not very much larger than the earth. This computation is of course based on the assumption that it is a miniature sun and intrinsically as bright as Sirius itself, perhaps a not very probable hypothesis. Indeed, the researches of Auwers on the irregularities in the proper motion of Sirius leads him to the conclusion that the mass of the small star is about half that of Sirius itself. This would make its mass about equal to that of the Sun, and would imply that it is nearly a dark body. We may therefore consider it as a giant planet revolving round Sirius at a distance comparable with that of Uranus from the Sun.

In the case of δ Cygni (magnitudes 3 and 8) we have a difference of five magnitudes between the components, indicating that the primary is 100 times brighter than the companion. As, however, we know nothing definitely of the distance of δ Cygni from the earth, it is impossible to compute the absolute dimensions of the components. The ratio of the diameters would, however, be—if of the same brilliancy—as 10 to 1, or about the same proportion which exists in the case of the Sun and Jupiter, and we may perhaps consider the companion as a giant planet in the sunlike stage of its existence.

We have the same relative brightness in the components of 85 Pegasi (magnitudes 6 and 11). An orbit recently computed for this binary by Mr. Schaeberle, combined with

a small parallax found by Brünnow, gives a combined mass of about 11 times the mass of the Sun. As the diameters of the components would be about 10 to 1—if of the same intrinsic brightness—their volumes would be in the ratio of 1000 (10^3) to 1. This would imply that the mass of the companion is about $\frac{1}{100}$th of the mass of our Sun, and its diameter (if of the same density) about 186,000 miles —possibly another giant planet in the sun-like stage.

From the above considerations we may, I think, conclude that some, at least, of the stars are centres of planetary systems, and form with our Sun members of one great stellar system, separated from each other by distances vastly greater than the dimensions of each system.

With reference to the clusters and nebulæ the distance of these objects has not yet been ascertained; but from the fact that stars, clusters, and nebulæ are mixed up in the greater Magellanic cloud in a space which is apparently of a globular form, we may conclude that clusters, nebulæ, and small stars may co-exist in the same region of space, and that consequently the nebulæ are not farther from the earth than the faint stars seen in the same direction.

In the cosmological speculations propounded by Lambert about the middle of the eighteenth century that "philosophical geometer" considered each star with its planetary train as forming a system of the "first order." He supposed the Sun and all the visible stars—except those belonging to the Milky Way—to form a great spherical cluster of stars in space. This he terms a system of the "second order." He then supposes a great number of these systems of the second order to be ranged on behind

the other in the Galactic plane, thus forming, by their united light, the phenomenon of the Milky Way.

This constitutes a system of the "third order," of a form not spherical but shaped like a disc, of which the diameter is vastly greater than the thickness, an arrangement somewhat similar to Struve's Galaxy. Lambert supposes that the universe contains a great number of Milky Ways, which, combined, form a system of the "fourth order"; and so on to systems of a higher order still. He did not consider the Milky Way as infinite in extent in the direction of its principal plane, and he estimates the distance of its remotest stars at about 150,000 times the distance of Sirius. He seems, however, to have overlooked the fact that stars at this vast distance would not be visible in the largest telescopes which could possibly be constructed. His view of the construction of the Milky Way is not, I think, supported by the general aspect of the Galactic Zone, an aspect which seems to suggest that it really forms *one* system, and not a great number of systems ranged one behind the other in space.

The modification of Lambert's hypothesis, which I have elsewhere supported (a similar view has also been advanced by Proctor[1]), is as follows:—

Suppose each sun with its attendant family of planets to form a system of the first order, as in Lambert's theory. All the visible stars, clusters, and nebulæ, the *Milky Way included*, are then assumed to form a system of the second order. Here, however, our positive knowledge ends. Our most powerful telescopes cannot penetrate beyond our own

[1] A similar hypothesis was also proposed by Sir John Herschel. See *Knowledge* for January 1886, p. 83.

system of the second order. But we can extend the analogy, and imagine other external systems of the second order to exist in space, which, combined with our visible universe, forms a system of the third order, and so on to higher orders still.

Assuming the distance of the faintest stars visible in our largest telescopes at 2300 times the distance of *a* Centauri (corresponding to the distance of a star of about the seventeenth magnitude), we have the diameter of our sidereal system—the visible universe—4600 times the distance of the nearest fixed star. Now the distance of *a* Centauri from the Sun is about 4500 times the diameter of Neptune's orbit. Hence, if we assume that the distance of the nearest external universe bears the same ratio to the diameter of our sidereal system that the distance between *a* Centauri and the Sun bears to the diameter of the Solar System, we have the following proportion :—

Diameter of Solar System : Distance between Solar Systems :: Diameter of sidereal universe : Distance between universes,

or 1 : 4500 :: 4600 × 4500 : Distance of nearest external universe,

from which we have

Distance of nearest external universe = 93,150,000,000 times the diameter of the Solar System, which multiplied by

5,584,000,000 = 520,149,600,000,000,000,000 miles,

a distance which light, with its amazing velocity of 186,300 miles per second, would take nearly 90,000,000 years to traverse!

At this vast distance, an external universe, if of the same diameter as our own, would subtend, if seen at all, an angle of less than one minute of arc, and would therefore appear only as a small and faint nebula.

It may perhaps be objected to the above calculation that our sidereal system may possibly extend much farther than 2300 times the distance of α Centauri; but if so, the distance of the nearest external universe will be proportionately increased and my argument thereby strengthened.

The above hypothesis affords an obvious explanation of the fact that the visible stars and nebulæ are limited in number. They all form part and parcel of one vast sidereal cluster—our visible universe—which is separated from all external galaxies by a vast starless void, in the same way that the Solar System is separated by empty space from the surrounding star sphere. The invisibility of the external universes may be explained on one or other of three assumptions.

1. The distance of even the nearest external universe is so great that its light has not yet reached the earth. In view, however, of the vast epochs of time indicated by geological history this supposition is perhaps improbable.

2. Beyond the bounds of our visible universe a "thinning out" of the luminiferous ether may occur, ending in an *absolute* vacuum which would of course arrest the passage of all light from outer space.

3. In the vast space which separates our sidereal system from its nearest neighbour an extinction of light may possibly take place in the ether which would thus act as a "cosmical veil," and for ever hide from our view all external galaxies.

It was argued by Struve that such an extinction does really take place, even within the limits of our sidereal system; but all the available evidence tends to show, I think, that there is no appreciable extinction of light, at least as far as our largest telescopes can penetrate into space. The case may, however, be far otherwise when external systems are concerned. The light of even the nearest of them, enfeebled by a distance of 20 million times that of α Centauri, might well be extinguished altogether by the absorption of light in such a vast thickness of a fluid medium, perhaps not absolutely perfect. I find that α Centauri placed at such a distance would—even if there were no absorption—be reduced to a star of about the thirty-sixth magnitude, which by Pogson's formula would require theoretically a telescope of over 24,000 feet in diameter even to glimpse!

We are not, however, precluded by this hypothesis from supposing that numerous similar systems exist in external space, and although we must consider the number of *visible* stars as strictly finite, the number of stars and systems really existing, but invisible to us, may be practically infinite. Could we speed our flight through space on angel wings beyond the confines of our limited universe, to a distance so great that the interval which separates us from the remotest fixed star visible in our largest telescopes might be considered as merely a step on our celestial journey, what further creations might not then be revealed to our wondering vision! Systems of a higher order might there be unfolded to our view compared with which the whole of our visible heavens might appear like a grain of sand on the ocean shore, systems perhaps stretching out

to infinity before us, and reaching at last the glorious "mansions" of the Almighty, the Throne of the Eternal! But here, dear reader, "I touch a theme too great for me to handle, but which will assuredly be handled by the loftiest minds when you and I, like streaks of morning cloud, shall have melted into the infinite azure of the past."

APPENDIX.

Note A.

The total mass of the Solar System may be taken as follows (earth's mass = 1):—

Sun	...	...	=	332,262
Jupiter	...	...	=	317
Saturn	...	...	=	95
Neptune	...	...	=	17·4
Uranus	...	...	=	14·6
Earth	...	...	=	1·0
Venus	...	...	=	0·8
Mars	...	...	=	0·11
Mercury	...	...	=	0·06
Satellites	...	...	=	0·20
Minor Planets	...	...	=	0·25
Total	...	...	...	332,708·42

Hence volume of globe equal in mass to the whole, and of the same specific gravity as the earth, would be—

$$7912 \times \sqrt[3]{332{,}708{\cdot}42} = 548{,}244 \text{ miles.}$$

Now, when the primeval nebulous mass extended as far as the orbit of Neptune, its diameter was—

$$2{,}792{,}000{,}000 \times 2 = 5{,}584{,}000{,}000 \text{ miles.}$$

Hence the density would be reduced in the ratio—

$$\left(\frac{548{,}244}{5{,}584{,}000{,}000}\right)^3 = \frac{1}{1{,}056{,}607{,}300{,}000}$$

of the earth's present density.

Assuming the earth's specific gravity at 5·67, we have—

$$\text{Density of nebula} = \frac{5{\cdot}67}{1{,}056{,}607{,}300{,}000} = \frac{1}{186{,}350{,}493{,}827}.$$

Now, as water is about 773 times heavier than air, and air 14·44 times the weight of an equal volume of hydrogen gas, we have water = 773 × 14·44 = 11,162 times the density of hydrogen at ordinary temperature and pressure. Hence

$$\text{Density of nebula} = \frac{11{,}162}{186{,}350{,}493{,}827} = \frac{1}{16{,}695{,}081}$$

of hydrogen, a result in close agreement with that found by Dr. Croll.

Note B.

With a "light ratio" of 2·512,

L = magnitude visible "by fits," with 1-inch aperture = 9·2 Pogson,

l = limiting magnitude for any given aperture,

Pogson's formula is—

$$l = \text{L} + 5 \log \text{aperture} = 9{\cdot}2 + 5 \log \text{aperture}.$$

From this formula we have the following:—

Aperture in inches.		Minimum visibile.	
3	... ...	11·58	magnitude.
4	... ...	12·2	,,
6	... ...	13·09	,,
8	... ...	13·7	,,
10	... ...	14·2	,,
12	... ...	14·59	,,
13	... ...	14·77	,,
14	... ...	14·9	,,
16	... ...	15·2	,,
18¼	(Herschel)	15·5	,,
20	... ...	15·7	,,
23	(Princeton Observatory)	16·0	,,

Aperture in inches.		Minimum visibile.
24	... ...	16·1 magnitude.
26	(Washington Observatory)	16·2 ,,
30	(Poulkowa ,,)	16·58 ,,
36	(Lick ,,)	16·98 ,,
60	(Mr. Common's Reflector)	18·09 ,,
72	(Lord Rosse's ,,)	18·48 ,,

Sir J. Herschel estimates that for metallic mirrors ratio of aperture of refractor to reflector with equal light is as 5 to 7. Hence 18¼-inch mirror = 13·03-inch refractor, and *min. visibile* would be about 14·77 mag. For Lord Rosse's telescope we have $\frac{72 \times 5}{7}$ = 51-inch refractor and *min. visibile* = 17·7 mag. For silver on glass mirrors the ratio is about 8 to 9, and therefore for Mr. Common's 5-feet reflector $\frac{60 \times 8}{9}$ = 53·33-inch refractor, and *min. visibile* = 17·8 mag. From this it appears that a star of 20 mag. would be far beyond the reach of any existing telescope.

Note C.

Points of Maximum Brightness of the Milky Way (Houzeau)

Nos.	R. A. = α.		Decl. = δ.	Mag.	Position.
	h.	m.	Deg.		
1	1	2	+ 61·0	5-6	To the north of β Cassiopeiæ.
2	2	12	+ 56·6	5-6	Nebula of Perseus.
3	3	4	+ 62·4	6-7	Between 2 Camelopardi and 5 Persei.
4	4	41	+ 40·8	6	Between ζ Aurigæ and ε Persei.
5	6	0	+ 23·0	5-6	A ⅓ of H to η Geminorum.
6	6	50	− 2·8	5-6	To the north of ε Monocerotis.
7	7	12	− 25·2	6	A ⅓ of ξ Navis to δ Canis Majoris.
8	7	58	− 47·4	6	A ⅓ of γ to R Navis.
9	10	39	− 59·2	5-6	Middle of Nos. 4448 and 4449 of Lacaille.
10	12	40	− 53·2	6	To the N.N.E. of β Crucis.
11	16	4	− 54·3	5	κ Normæ.
12	16	40	− 46·6	5-6	Between η Scorpii and ε Normæ.
13	16	47	− 40·8	5-6	To the N.N.E. of ξ Scorpii.
14	16	52	− 32·6	6	Near ρ Cygni.
15	17	30	− 17·4	6-7	To the south of ξ Serpentis.

Points of Maximum Brightness of the Milky Way (Houzeau)—continued.

Nos.	R. A. = α.		Decl. = δ.	Mag.	Position.
	h.	m.	Deg.		
16	17	35	− 22·5	6	Near D Ophiuchi.
17	17	46	− 34·7	4	Nebula 7 Messier.
18	18	0	− 28·5	5	Round 716 Mayer.
19	18	8	− 18·7	4-5	To the north of μ Sagittarii.
20	18	21	+ 4·8	6	Near r Ophiuchi.
21	18	23	− 14·4	5	Near s Clypei.
22	18	24	− 18·9	5-6	Between 728 and 729 Mayer.
23	18	41	− 7·0	4-5	Between l and n Aquilæ.
24	18	48	+ 11·6	6	Near 18 Aquilæ.
25	18	56	− 1·2	6	Between θ Serpentis and λ Aquilæ.
26	19	32	+ 11·8	5-6	Near χ Aquilæ.
27	19	43	+ 29·1	5-6	To the E.N.E. of β Cygni.
28	20	3	+ 36·0	5-6	Between b_1 and b_2 Cygni.
29	20	40	+ 31·0	6	Near κ Cygni.
30	20	57	+ 35·2	6	Between λ and υ Cygni.
31	21	2	+ 45·5	5	Between ξ and f_2 Cygni.
32	21	25	+ 47·5	5-6	Between π_1 and g Cygni.
33	22	15	+ 51·0	6	Near o Lacertæ.

Note D.

Sir John Herschel gives the following results of the gauges in the Northern and Southern Hemispheres (*Outlines of Astronomy*, para. 795, 796, Tenth Edition).

Northern Hemisphere.

Zones of Galactic North Polar Distance.					Average Number of Stars per Field of 15′.
Deg.		Deg.			
0	to	15	...	...	4·32
15	,,	30	...	...	5·42
30	,,	45	...	...	8·21
45	,,	60	...	...	13·61
60	,,	75	...	...	24·09
75	,,	90	...	...	53·43

Southern Hemisphere.

Zones of Galactic South Polar Distance. Deg.		Deg.	Average Number of Stars per Field of 15′.
0	to	15	6·05
15	„	30	6·62
30	„	45	9·08
45	„	60	13·49
60	„	75	26·29
75	„	90	59·06

Note E.

Distribution of the Naked-eye Stars with reference to the Milky Way, according to Houzeau.

	Magnitudes.						Total.	Density.
	1	2	3	4	5	6		
Northern Cap .	0	1	4	8	42	86	141	0·113
3rd Zone, North	3	6	18	42	74	295	438	0·122
2nd „ „ .	1	4	21	70	148	439	683	0·124
1st „ „ .	4	7	34	114	190	625	974	0·145
Middle . .	7	11	46	108	243	730	1145	0·160
1st Zone, South .	3	11	34	111	257	619	1035	0·154
2nd „ „ .	0	7	28	65	141	465	706	0·129
3rd „ „ .	2	2	13	65	81	281	444	0·124
Southern Cap .	0	2	2	12	37	100	153	0·123
Total . .	20	51	200	595	1213	3640	5719	0·139

Note F.

The area of each division in square degrees may be determined as follows:—

Set δ = declination of northern limit of zone.

and

δ^1 = „ southern „

Then area of zone $= 360 \times 57{\cdot}296 (\sin \delta - \sin \delta^1)$.

„ „ $= 20626{\cdot}5 \times (\sin \delta - \sin \delta^1)$.

The area thus found must of course be divided by 36, to obtain the area of each division of $10° \times 10°$.

NOTE G.

Number of Stars given in different Catalogues, excluding Variable Stars, Nebulæ, and Clusters.

Magnitudes.	Northern Hemisphere.			Southern Hemisphere.	
	Heis.	Harvard Photometry.	Oxford.	Uranometria Argentina.	Behrmann.
Brighter than 1·1 . .	4	27	5	5	...
1·1 to 2·0 (both inclusive)	24		13	14	...
2·1 „ 3·0 „ „	55	71	44	66	...
3·1 „ 4·0 „ „	175	229	138	167	...
4·1 „ 5·0 „ „	461	741	421	323	...
5·0 „ 5·5 „ „	...	845	...	...	...
5·1 „ 6·0 „ „	1640	...	1287	1247	...
Total to 6·0 „ „	2359	1913	1908	1822	2306
6·1 to 7·0 „ „	...	...	...	4872	(to 6th mag. between −20° and −90°).
6-7 mag. (Heis) . .	1544	...	...	...	
6·1 to 6½ (U.A.) . .	...	...	...	1395	
6-m. stars (Argelander and others) measured	...	...	...	...	...
below 6·0 . . .	...	...	491	...	...
Stars seen by Heis 0° to −20°	1040	...	...	...	...

N.B.—The results given above for the Harvard Photometry are due to Mr. Monck.

Summary of above results.

Total number of stars seen by Heis in Northern Hemisphere, to 6-7 magnitude—

$$= 2359 + 1544 = 3903.$$

Total number of stars in *Uranometria Argentina*, in Southern Hemisphere, to 6·5 magnitude—

$$= 1822 + 1395 = 3217.$$

Total number of stars to 6·0 magnitude in both Hemispheres, Heis and Gould—

$$= 2359 + 1822 = 4181.$$

Total number of stars seen with the naked eye by Heis and Behrmann in both Hemispheres—

$$= 2359 + 1544 + 1040 + 2306 = 7249.$$

Let x = distance, and n difference of magnitude
then $x^2 = 2.512^n$ or $\log x = 0.2\,n$

NOTE H.

Distances of Stars of Different Magnitudes.

Light ratio 2·5119.

(On the assumption that there is no extinction of light in space.)

Magnitude.	Distance.
1·00	1·000
2·00	1·585
3·00	2·512
4·00	3·981
5·00	6·310
6·00	10·000
7·00	~~15·485~~ 15.849
8·00	25·119
9·00	39·811
10·00	63·096
11·00	100·000
12·00	158·489
13·00	251·189
14·00	398·107
15·00	630·957
16·00	1000·000

NOTE I.

Stars with Annual Proper Motion of more than 2″.

Star.	Mag.	R.A., 1890.	Declination, 1890.	Motion per Annum.	Remarks.
		h. m. s.	deg. min.	sec.	
Groombridge 1830	6·5	11 46 38	+38 30·5	7·0	Place from Greenwich, Ten-year Cat., 1880.
Lacaille 9352 .	7·2	22 58 46	−36 29·2	6·9	...
Cordoba 32416 .	8·2	23 59 0	−38 16	6·1	...
61 Cygni . .	5·1	21 1 58	+38 12·5	5·2	Double.
Lalande 21185 .	7·3	10 57 19	+36 42·4	4·7	Place from Greenwich, Ten-year Cat., 1880.
ϵ Indi . . .	5·2	21 54 6	−57 14·3	4·6	...

Stars with Annual Proper Motion of more than 2″ (continued).

Star.	Mag.	R.A., 1890.	Declination, 1890.	Motion per Annum.	Remarks.
		h. m. s.	deg. min.	sec.	
Lalande 21258	8·6	11 0 0	+44 5·5	4·4	Place from Greenwich, Ten-year Cat., 1880.
40 Eridani	4·4	4 10 13	− 7 49·2	4·1	Triple.
μ Cassiopieæ	5·2	1 0 57	+54 22·8	3·7	...
α Centauri	−0·5	14 32 8	−60 22·7	3·7	Double.
A.-Oe. 14318	9·2	15 4 0	−15 56	3·6	...
A.-Oe. 14320	9·0	15 4 0	−15 51		
Lacaille 8760	7·6	21 10 53	−39 17·2	3·4	...
e Eridani	4·4	3 15 30	−43 29·5	3·0	...
A.-Oe. 11677	9·0	11 14 21	+66 26·5	3·0	Place from Greenwich, Ten-year Cat., 1880.
Groombridge 34	7·9	0 12 6	+43 23·9	2·8	Double.
Piazzi II. 123	6·3	2 30 3	+ 6 21·1	2·4	Place from Greenwich, Ten-year Cat., 1880.
Lalande 25372	8·0	13 40 10	+15 29·3	2·3	Do.
α Boötis	0·2	14 10 39	+19 45·6	2·3	Do.
Struve 2398	8·5	18 41 33	+59 27·7	2·3	Double.
β Hydri	3·0	0 19 49	−77 52	2·2	...
Lalande 7443	8·5	3 55 52	+35 0·4	2·2	Place from Greenwich, Ten-year Cat., 1880.
Weisse V. 592	9·5	5 26 0	− 3 40	2·2	...
Bradley 3077	5·9	23 7 59	+56 33·7	2·1	Place from Greenwich, Ten-year Cat., 1880.
ζ Tucanæ	4·1	0 14 20	−65 31·3	2·0	...
Lalande 15290	8·3	7 46 31	+30 56·6	2·0	Place from Greenwich, Ten-year Cat., 1880.
Piazzi XIV. 212	5·9	14 51 2	−20 55·0	2·0	Do.

NOTE J.

Parallax and Velocity of Stars with Large Proper Motions.

Star.	Mag.	Proper Motion.	Parallax.	Velocity. Miles per Second.	Light Journey. Years.
		Sec.	Sec.		
Groombridge 1830	6·5	7·0	0·089	231	36·6
Lacaille 9352 .	7·2	6·9	0·285	71·2	11·4
61 Cygni . .	5·1	5·2	0·45	34·0	7·2
ϵ Indi . . .	5·2	4·6	0·20	67·7	16·3
Lalande 21258 .	8·6	4·4	0·262	49·4	12·4
40 Eridani . .	4·4	4·07	0·166	72·1	19·6
μ Cassiopeiæ .	5·2	3·7	0·036	302·5	90·5
A.-Oe. 11677 .	9·0	3·0	0·10	88·3	32·6
ϵ Eridani . .	4·4	3·0	0·14	63·0	23·3
α Boötis . .	0·2	2·3	0·018	376	181
ζ Tucanæ . .	4·1	2·0	0·06	98·1	54·3
85 Pegasi . .	5·8	1·22	0·054	66·5	60·3
θ Ursæ Majoris .	3·2	1·1	0·046	70·3	70·8

NOTE K.

If λ = wave length of ray when the observer and star are relatively at rest,

λ^1 = wave length affected by relative motion,

V = velocity of light (= 186,400 miles per second),

v = velocity of approach,

Then

$$\lambda^1 = \lambda \cdot \frac{V}{V + v}$$

$$\therefore \lambda - \lambda^1 = \lambda - \lambda \frac{V}{V + v}$$

or,

$$\lambda - \lambda^1 = \lambda \cdot \frac{v}{V + v}$$

whence

$$v = \frac{V(\lambda - \lambda^1)}{\lambda^1}.$$

For a motion of recession—

$$\lambda^1 = \lambda \cdot \frac{V}{V - v}$$

$$\therefore\ \lambda^1 - \lambda = \lambda \cdot \frac{v}{V - v},$$

and

$$v = \frac{V\,(\lambda^1 - \lambda)}{\lambda^1}.$$

Mr. Keeler of the Lick Observatory has observed and measured a displacement of the chief nebular line in several planetary nebulæ. In the nebula N.G.C. 6790 he found a displacement of + 1·03 of a tenth-metre, indicating a motion of recession from the earth. Now, taking the wave-length, λ, of the chief nebular line at 5006·71, we have $\lambda^1 = 5006{\cdot}71 + 1{\cdot}03 = 5007{\cdot}74$. Hence

$$v = \frac{186{,}400 \times 1{\cdot}03}{5007{\cdot}74} = 38{\cdot}3 \text{ miles per second.}$$

Note L.

The problem of determining the relation between the mean distance (taken as unity) of two neighbouring stars, and the radius r of the sphere, which contains N stars uniformly distributed, has been treated by Lambert, Sir W. Herschel, and Schubert. As, however, the question has been treated from a different point of view by each computer, the results do not agree very well. According to Struve[1] all solutions should fulfil the fundamental condition that the number of stars contained in the interior of a sphere be proportional to the volume of the sphere. This is evident. "According to this condition we should have $\frac{4}{3}\pi r^3 : N = s$, and s would be the unit of space by which the volume increases for each additional star, or the modulus of volume for each star." To find from s the mean distance between two neighbouring stars, Struve supposes the geometric form of the module to be a tetrahedron, the length of the edge of this pyramid (= 1) determining the mean distance required. The volume of such a pyramid being $s = \frac{1}{12}\sqrt{2}$, we have—

$$\frac{4}{3}\,\frac{\pi r^3}{N} = \frac{1}{12}\sqrt{2},$$

[1] *Études d'Astronomie Stellaire*, Note 41.

or—

$$16\,\pi r^3 = N\sqrt{2},\ \text{and}\ \therefore\ r = \sqrt[3]{\frac{N\sqrt{2}}{16\,\pi}} = \sqrt[3]{\frac{N}{35{\cdot}573}}.^1$$

Now, if in the field of a telescope of which the apparent radius $= \lambda$, expressed in seconds of arc, the number of visible stars $= n$, we have for the number of stars N visible on the whole celestial vault, supposing a regular distribution,

$$N = \frac{4\,\pi}{\sin \lambda^2}\,n,\ \text{and}\ r = \sqrt[3]{\frac{n\sqrt{2}}{4 \sin \lambda^2}} = 2468{\cdot}5\sqrt[3]{\frac{n}{\lambda^2}}.^1$$

Note M.

Enumeration of Stars in Harding's Atlas to 8th mag. Inclusive.

Hour.	0° to +15°. No. of Stars.	0° to −15°. No. of Stars.	Total.	Remarks.
0— 1	143	169	312	...
1— 2	120	155	275	...
2— 3	136	151	287	...
3— 4	124	187	311	...
4— 5	226	233	459	Hyades near N limit of zone.
5— 6	246	267	513	Orion.
6— 7	329	272	601	Milky Way.
7— 8	273	244	517	...
8— 9	254	230	484	...
9—10	210	235	445	...
10—11	232	232	464	...
11—12	223	173	396	...
12—13	218	186	404	Nebular region, North.
13—14	179	192	371	...
14—15	231	189	420	...
15—16	209	180	389	...
16—17	231	196	427	...
17—18	306	213	519	...
18—19	340	271	611	Milky Way.
19—20	323	243	566	" "
20—21	289	278	567	...
21—22	211	213	424	...
22—23	189	192	381	...
23—24	153	177	330	...
Total .	5395	5078	10,473	...

[1] *Études d'Astronomie Stellaire*, Note 41.

Note N.

The papers referred to in the text are as follows :—

1786. Catalogue of One Thousand New Nebulæ and Clusters of Stars.

1789. Catalogue of a Second Thousand of New Nebulæ, etc.

1791. On Nebulous Stars properly so called.

1794. On the Nature and Construction of the Sun and Fixed Stars.

1796. Method of observing the Changes that happen to the Fixed Stars, etc.

1799. On the Power of penetrating into Space by Telescopes.

1802. Catalogue of 500 New Nebulæ, etc.

1806. On the Quantity and Velocity of the Solar Motion.

1811. Astronomical Observations relating to the Construction of the Heavens.

1814. Astronomical Observations relating to the Sidereal Part of the Heavens, and its Connection with the Nebulous Part.

1817. Observations and Experiments on the Local Arrangement of the Celestial Bodies in Space, and to determine the extent of the Milky Way.

1818. Observations and Experiments for ascertaining the Distances of Clusters of Stars, and investigating the Power of our Telescopes.

Note O.

Herschel computes the penetrating power p of a telescope in the following way:[1]—If S denotes the sum of the rays of light which the instrument conveys to the eye, and s the sum of the rays gathered by the eye pupil, then $p = \sqrt{\frac{S}{s}}$. If A is the clear aperture of the mirror or object glass, and a that of the pupil of the eye = 0·2 inch, and μ a co-efficient which denotes the relation between the quantity of light which falls on the object glass and that which issues from the eye piece, we have $\frac{S}{s} = \mu \frac{A^2}{a^2}$, whence $p = \frac{A}{a}\sqrt{\mu}$. In the Newtonian reflector with a small mirror of which the minor axis = b, the formula becomes $p = \sqrt{\mu \cdot \frac{A^2 - b^2}{a^2}}$. Herschel determined μ by direct experiments on the loss of light by reflection, and by passage through lenses. In this way he found the following penetrating powers for his different telescopes:—

	Aperture in inches.	p.	
1. No. 4	0·75	3·56	Ordinary telescope.
2. No. 8	1·17	4·50	Achromatic „
3. Small Sweeper of 2 ft.	4·2	12·84	Newtonian reflectors with small mirror.
4. Telescope of 7 ft. ...	6·3	20·25	
5. Large Sweeper of 5·2 ft.	9·2	28·57	
6. Telescope of 10 ft. ...	8·9	28·67	
7. Small Telescope of 20 ft.	12·0	38·99	
8. Large Telescope of 20 ft.	18·8	61·18 75·08	
9. Large Telescope of 25 ft.	24·0	95·85	Telescopes with the "front view."
10. Large Telescope of 40 ft.	48·0	191·69	

No. 4 was the instrument with which Herschel discovered

[1] *Études d'Astronomie Stellaire*, Note 59.

Uranus and made two catalogues of doubles. It was of high optical excellence.

No. 8 was the principal instrument used by Herschel in his gauges. First used with a small mirror, afterwards improved by the "front view" construction.

No. 10 was the great telescope constructed in 1789, and with which Herschel discovered the two minor satellites of Saturn, Mimas and Enceladus.

In his researches on the penetrating power of telescopes Herschel does not take into account the magnifying power used, but says that if the telescope is to act with its full power, the power should be greater than $\frac{A}{a}$. For the gauging telescope $A = 18{\cdot}8$, and $a = 0{\cdot}2$, and therefore $\frac{A}{a} = 94$ is the smallest magnifier which should be employed with that telescope. The power used by Herschel in the sweeps and gauges was 157.[1]

NOTE P.

Table of Relative Distances (Struve).

Apparent Magnitude.	Distance of Interior Limit.	Mean Distance.	Distance of Exterior Limit.
1 Argelander . . .	...	1·0000	1·2638
2 „ . . .	1·2638	1·8031	2·1408
3 „ . . .	2·1408	2·7639	3·1961
4 „ . . .	3·1961	3·9057	4·4374
5 „ . . .	4·4374	5·4545	6·2093
6 „ . . .	6·2093	7·7258	8·8726
6 Bessel	...	...	8·2160
7 „	8·2160	...	14·4365
8 „	14·4365	...	24·8445
9 „	24·8445	...	37·7364
Herschel's faintest . .	...	...	227·782

[1] *Études d'Astronomie Stellaire*, Note 59.

NOTE Q.

The following table shows the number of stars to any given magnitude which should *theoretically* be visible, according to Dr. Gould's formula—

$$\Sigma_m = 1{\cdot}0051 \times (3{\cdot}9120)^m.$$

Magnitude.	No. of Stars.	Magnitude.	No. of Stars.
To 1·0 inclusive	3·93	To 10·0 inclusive	843,718
„ 2·0 „	15·74	„ 11·0 „	3,283,876
„ 3·0 „	60·17	„ 12·0 „	12,911,448
„ 4·0 „	235·4	„ 13·0 „	50,511,900
„ 5·0 „	920·9	„ 14·0 „	197,602,545
„ 6·0 „	3,602·5	„ 15·0 „	773,021,071
„ 7·0 „	14,093	„ 16·0 „	3,024,057,632
„ 8·0 „	55,131	„ 17·0 „	11,830,114,720
„ 9·0 „	215,674		

From this it appears that if the stars were uniformly scattered through space, and light suffered no extinction, the number of stars visible in the Lick telescope would be about 11,000 millions, or over 266,000 stars to each square degree!

Another way of looking at the question is as follows:—Assuming that the smallest star visible in the Lick telescope is of the 17th mag., we have, with a light ratio of 2·512,—

Light of star of 6th mag. $= (2{\cdot}512)^{11} \times$ light of 17th-mag. stars,

or,

Star of 6th mag. $= 25{,}120 \times$ light of 17th mag.

If, therefore, of the same size and brightness, the distance of a 17th-mag. star will be $\sqrt{25{,}120} \times$ distance of 6th-mag. star. Hence, volume of space at distance of 17th-mag. star will be—

$(25{,}120)^{\frac{3}{2}} \times$ volume of sphere containing all stars to the 6th mag.,

or,

3,981,100 times the volume of sphere containing 6th mag.

Now, supposing an equal distribution of stars, and the total number in both hemispheres to 6th mag. inclusive, as 4000 in round numbers (*see* Note G), we should have the total number of stars visible in the Lick telescope—

$$3{,}981{,}100 \times 4000 = 15{,}924{,}400{,}000.$$

The "light ratio" derived from Gould's formula is 2·4827. This partly accounts for the discrepancy between the result computed above and that given in the preceding table.

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[1] Now Lord Kelvin.

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